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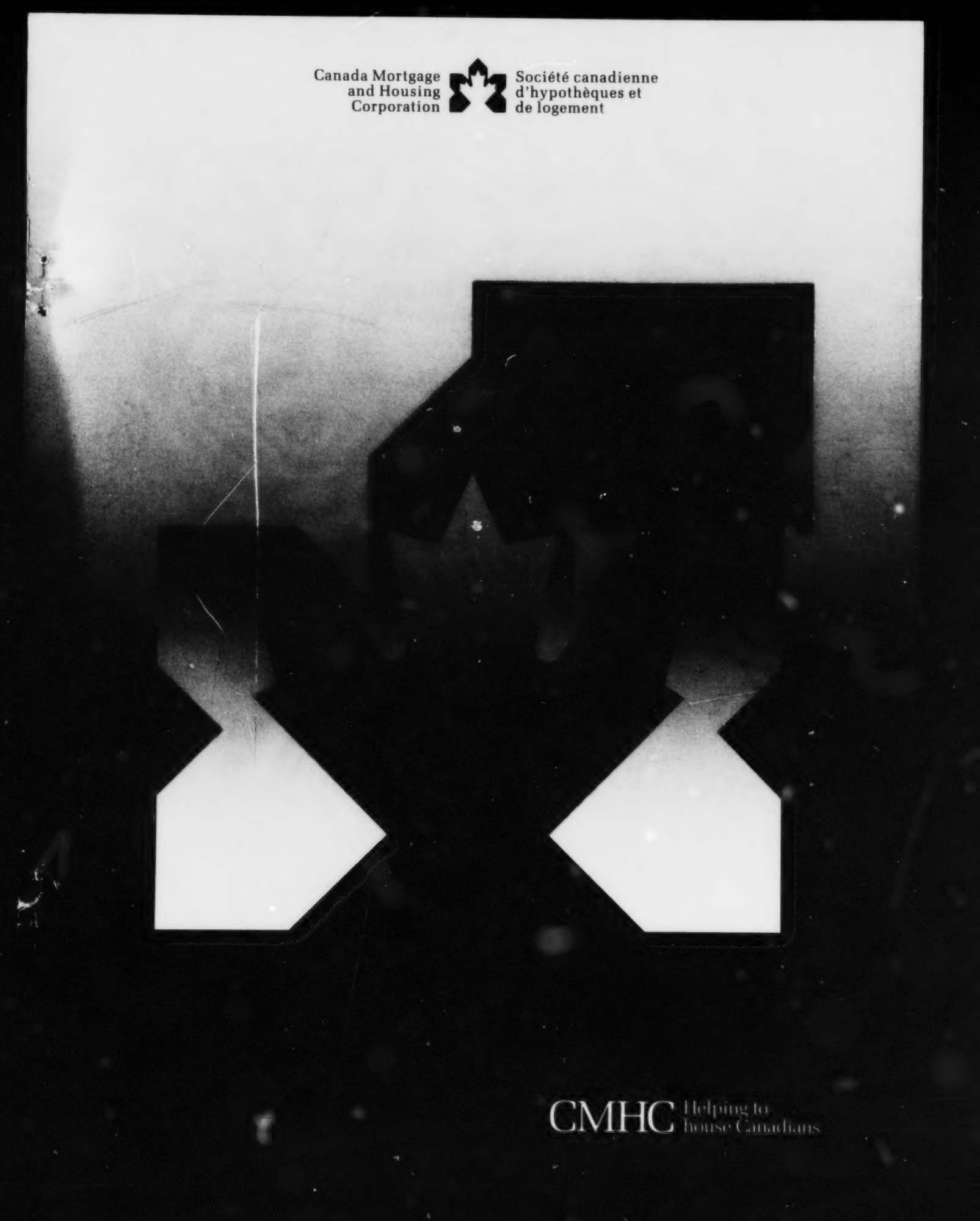

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# A NEW METHOD OF MAKING WAFERBOARD BY AUTO-BONDING

March 1987

# A NEW METHOD OF MAKING WAFERBOARD BY AUTO-BONDING

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## ABSTRACT

Poplar waferboard can be made without using synthetic resins, by the auto-bonding process. Auto-bonding is achieved by subjecting green wafers to a high pressure steam (210 to 250 degrees C) for a short period of time (30 seconds to 12 minutes) to induce a thermal chemical transformation. Essentially, the steam decomposes and hydrolyzes hemicellulose portions of the poplar wafers into low molecular weight water soluble carbohydrates of a monomeric and oligomeric nature. These water soluble carbohydrates when heated under high temperature and pressure further undergo transformation and polymerization to form an insoluble and irreversible crosslinked polymeric substance. This polymeric substance acts as an adhesive bond "in situ" to provide both a bonding and bulking effect, producing a boilproof waferboard with superb dimensional stability. Consumption of steam is one of the major production costs for the new waferboard. In order to obtain an auto-bonded waferboard which meets the new national standards (1), thinner wafers than those required for conventionally bonded board and a slightly higher board density, (42 - 44 pcf as opposed to a 40 pcf) are necessary. Also, the auto-bonded waferboard requires longer press times to cure than conventional waferboard. The elimination of synthetic resin and wax, however considerably reduces production costs for the new waferboard. Furthermore, the auto-bonding process is ideal for the production of a 3-layer construction, wafer-fibre-wafer or wafer-particle-wafer board, using low cost mill residues for core stock and further reducing production cost. This new process for making waferboard has a good potential for industrial applications.

## EXECUTIVE SUMMARY

Waferboard was first produced in Canada in 1961. The process uses poplar logs which are first cut into thin wafers, dried, mixed with a powdered phenolic resin and wax, and then bonded under heat and pressure to form a rigid panel product. Waferboard is comparable to sheathing grade plywood made from softwood and, to a large degree, has come to replace plywood in most structural and utility construction applications.

Including the oriented strandboard (OSB) plants, there are 15 waferboard plants in Canada. The total shipment value of waferboard in 1986 is estimated to be over 300 million dollars. In the U.S.A. there are numerous new plants with a combined annual capacity in North America of over 6 million $M^3$. Factories now under construction and mills planned to be built within the next few years will reinforce the manufacturing of waferboard in Canada and will make it a major forest products industry to be reckoned with.

The industry thus far has relied upon highly developed synthetic resin binders (phenol formaldehyde) and slack wax as the essential components in the production of waferboard. However, since phenolic resin is derived from petro-chemicals, it has become increasingly expensive, prompting a search for alternative resin binders. For the past decade or so, researchers have attempted to develop resin binders from renewable resources, including lignin from waste pulping liquor, tannin from tree bark, whey from dairy products and carbohydrates from food processing. However, none of these proposed alternatives has been successfully developed to a commercial level for technical or economic

reasons.

The new process, auto-bonding, developed and patented by Dr. Shen is essentially and fundamentally different from the conventional method of manufacturing waferboard because it eliminates the need for phenolic resin and wax altogether. The new process actively generates a bonding agent from within the lignocellulosic material. This auto-bonding technique is achieved by converting the hemicellulose portion of the lignocellulosic material through auto-hydrolysis. Green wafers are subjected to high temperature steam for a short period of time which produces low molecular weight water soluble carbohydrates of monomeric and oligomeric nature which can be polymerized under heat and pressure acting as a bonding agent "in situ", thereby producing a waferboard that meets and exceeds CSA standards.

The auto-bonding process is simple since it requires only a steam pretreatment of green wafers before the conventional procedures. Significant advantages are realized with the elimination of the resin and wax blending steps. The steam treatment is the essential step to the Shen process. A steam temperature within the range of 210 degrees to 250 degrees Celsius in combination with a duration ranging from 45 seconds to 12 minutes has proven to be effective to achieve auto-bonding, resulting in a waferboard with good physical strength and superb dimensional stability.

Thinner or small size wafers appeared to produce a more uniform mat and thus a better quality waferboard. Since the bonding agent is generated from within, this new process, unlike the conventional process, allows for 100% utilization of wood material including the undersized wafers, splinters and fines generated in waferization which are normally

rejected and used as fuel. Furthermore, particles and fibres, which can be converted from low cost mill residues can be effectively utilized as core stock to replace at least 50% of wafers which must be cut from poplar logs in the manufacture of waferboard. In addition, it was found that a three-layer waferboard, consisting of 50% thin wafers on the surface layers and 50% particles or fibres in the core, produces an excellent auto-bonded waferboard.

The curing rate of the auto-bonding process, when compared with the conventional process, is much slower than the phenolic bonded waferboard and therefore requires twice the press time. However, with the addition of an acidic catalyst, the curing rate can be improved considerably but still requires a 20 to 30% longer press time than conventionally bonded board.

With the auto-bonding process there is a mass loss during the wafer steam treatment and hot pressing. The combined weight loss is approximately 10 to 15% of the total initial weight. This loss is due to a thermo-chemical transformation and appears to be a characteristic phenomenon of the auto-bonding process. Auto-bonded waferboard is heavier in weight than conventional waferboard by approximately 5 to 10%. In addition, the auto-bonding process consumes more heat energy than the conventional method because of the steam treatment and longer press time. It is estimated that about two tons of steam is required to treat one ton of wafers (based oven dry weight). The higher energy and wood consumption will increase the production cost by approximately 5 - 7%.

However, in the Shen auto-bonding process, with the elimination of resin and wax and the replacement of 50% or more of the wafers with low cost mill residue, it is estimated that a 37% reduction in production

costs shall be realized. In contrast, only 5 - 7% extra costs are consumed by the auto-bonding process. All factors taken into account, the new process can lower waferboard production costs by about 30 - 32%, which is a significant amount.

The most effective demonstration of the potential which the auto-bonding process can realize would be the design and construction of a new board plant suited to the Shen process. The capital investment for an auto-bonding waferboard plant would be very comparable to that of a conventional plant. For an existing waferboard plant, the economics of the auto-bonding process may be less attractive. This is mainly due to the longer pressing times required, which would reduce the production capacity considerably.

Further work is required to improve the existing system and develop alternative solutions to reduce pressing times. For example, different catalysts as well as other novel techniques which can shorten pressing time should be examined in detail. As well, the long term durability of the auto-bonded waferboard should be studied, particularly in association with the use of acidic catalysts. It is evident that auto-bonded waferboard will negate the industry's dependence on petrochemically based resins and, with further development, become economically viable and technically attractive to the industry.

## 1. BACKGROUND

Waferboard was invented by Dr. J. d'A Clark in the United States during the early fifties. Waferboard is made almost exclusively from poplar logs by cutting them into thin wafers, then screening, drying, blending the wafers with powdered phenolic resin, felting a mat and pressing it under heat and pressure to form a rigid and bonded panelboard. Waferboard is comparable to and competes with softwood plywood in all structural and utility construction applications. The first Canadian waferboard plant was built in 1961 at Hudson Bay, Saskatchewan, with a daily capacity of 120 tons (2). After a quarter of a century, there are now 15 waferboard plants (including OSB plants) operating in Canada, with a total production capacity of 2.3 billion square ft. (3/8 inch basis), with the product having a market value of more than 300 million dollars in 1986. Similarly, there are approximately 20 plants operating in the United States with a combined production capacity of 6 million $M^3$. It is expected that waferboard production will continue to increase in the future, in both countries, as new plants under construction and those under consideration come into operation.

The industry thus far has relied upon the use of highly developed synthetic resin binders. Since the synthetic resin binders are derived from petrochemicals, they have become increasingly expensive, promoting a search for alternative resin binders. For the past decade or so, researchers have attempted to develop resin binders from renewable resources. Among other things, lignin from the pulping waste liquor, tannin from tree bark, whey from dairy products and carbohydrates from food processing have been proposed as possible alternative binders (3,4,5 and 6). In addition, there are a few research reports indicating the

possibility of bonding lignocellulosic material without the use of synthetic resins. In order to achieve a permanent bond, application of chemicals and catalytic modifications to lignocellulosic material was necessary (7,8 and 9). However, none of these new resins and methods has been successfully developed at the commercial level for technical or economic reasons.

A new method for making composite products from lignocellulosic material has been developed and patented in Canada (10). This new process of making waferboard is essentially different from the conventional process or other experimental systems because it eliminates the need for resin binders altogether and requires no chemicals or catalytic modification at all. This revolutionary auto-bonding technique is achieved by converting the hemicellulose portion of the lignocellulosic material through autohydrolysis into low molecular weight monomer and oligomeric water soluble carbohydrates, sugar polymers, furfural products, dehydrated carbohydrates, organic acids and other decomposition products which then polymerize under heat and pressure to act as a bonding agent "in situ", providing a waferboard which is comparable to the commercial waferboard in physical properties but at a reduced cost. The new auto-bonding process is thus superior to the conventional method in important technical and economical merits.

It is believed that the new bonding is created by the chemical transformation of monomeric and oligomeric carbohydrates and other decomposition products from hemicellulose hydrolysis. The theoretical aspects of the chemical reaction or reactions involved in the new auto-bonding process have not been fully understood, but the new process has been found to work satisfactorily with all kinds of lignocellulosic

material, including both woody and non-woody plants (11).

## 2. OBJECTIVES

The primary objective of this project is to demonstrate that poplar waferboard can be made by the auto-bonding process without the use of synthetic resin and wax. The secondary objective is to optimize processing parameters which will ultimately produce an auto-bonded waferboard with adequate physical properties at a minimum cost. The third objective is to collect all technical and economical information on which future R & D work and accurate economic data can be built, leading to commercial application of the auto-bonding process.

## 3. METHODS AND MATERIALS

### 3.1 Wafer Preparation

Debarked green poplar (Populus tremuloides) logs purchased from the vicinity of Killaloe, Ontario were waferized and used in this project. Wafers of three nominal thicknesses (0.012, 0.020 and 0.028 inch) of 1 1/2 inch length and random width, but generally in the order of 1/2 to 3 inch, were cut from the green poplar bolts using a CAE Laboratory Waferizer. After waferization, the wafers were packed into a plastic bag and stored in a cool and wet chamber in preparation for steam treatment. The moisture content of green wafers ranged from 90 to 160%, based on the oven dry (O. D.) weight of the wafers.

### 3.2 Steam Treatment

Two types of steam treating vessels were used in this project.

Initially, a modified steam press at Forintek was used to treat wafers with a lower range of steam temperature of 210 degrees C , or at 262 psi of steam pressure (11). Later, a cylindrical tank 10 inches in diameter and 36 inches in length (Figure 1) of 1 1/2 cubic ft capacity was constructed for higher pressure treatments up to 560 psi or 250 degrees C. The pressure tank was equipped with a steam inlet and a steam outlet valve, along with a safety valve and a condensate collecting device. The main tank was insulated with R-20 rated fibre glass.

The green wafers were first loosely packed in a perforated stainless steel basket (Figure 1). The basket, with wafers, was weighed and then loaded into the pressure vessel. After sealing the pressure vessel, saturated steam, at a predetermined pressure, supplied by an electrical steam boiler, (Figure 2) was introduced through an inlet valve for a specified period of time. During this period steam pressure within the vessel was maintained at the desired level. At the end of the steaming, the inlet valve was shut off and the outlet valve was opened to release the steam to atmospheric pressure before unloading the basket. The basket was again weighed and the steam treated wafers were removed for drying. There was, during steaming, a loss of moisture of the green wafers. The loss of moisture varied from about 30 - 60% depending upon the initial moisture content of the green wafers, the severity of the treatment and the manner by which the pressure was released. In addition, there was a loss in mass of the wafers, resulting from the escape of volatile and gaseous material derived from the decomposition and hydrolysis of poplar wafers by the steam treatment. This loss in weight was in the range of 3 to 6%, depending mainly on the severity of the treatment. The steam treated wafers were brownish in colour and the

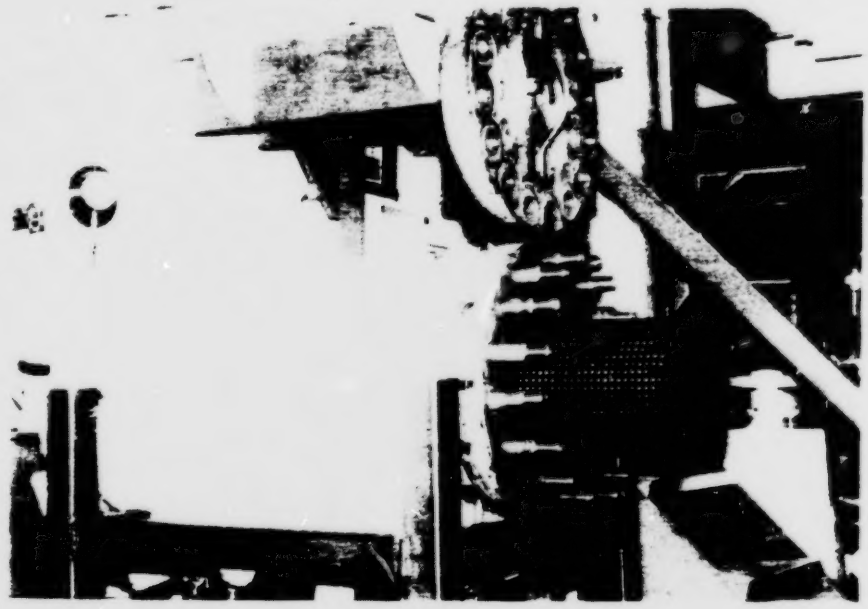


FIGURE 1. THE 1 1/2 CUBIC FOOT HIGH PRESSURE VESSEL. METAL LOADING BASKET PARTIALLY INSERTED IN VESSEL

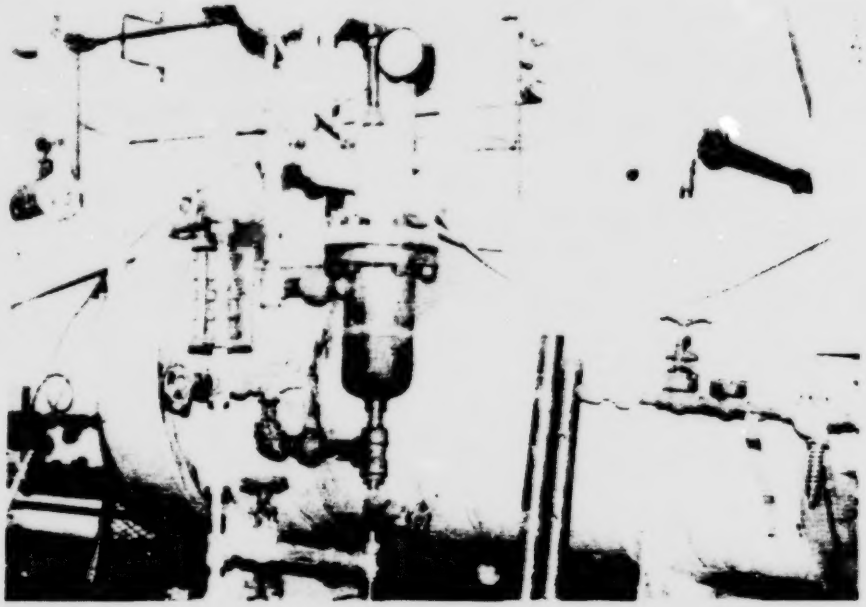


FIGURE 2. THE HIGH PRESSURE ELECTRICAL STEAM BOILER USED IN THE PROJECT

intensity of their colour was related to the degree of treatment. The treated wafers were air dried to a moisture content of 4-6% and then placed in plastic bags for board fabrication. The dried wafers were chemically stable and could be stored for months without any adverse effect. In some cases, the dried wafers were separated into two fractions by screening with a 1/4 inch mesh screen. The larger wafers were used for surface layers and the smaller ones for the core layer of the boards to be fabricated. In some cases, the smaller sized wafers were hammer milled to further refine the wafers into fibrous bundles or particulates for the core part of the waferboard. The core wafers were often dried to a lower moisture content of 2-3%, in comparison to surface wafers with 4-6% moisture content. In all cases, there was no removal of under sized wafers, splinters, particles, and fines, thus 100% of the wafers, regardless of size and shape, were used in board manufacturing. This is contrary to conventional practice in which the under sized wafers or fines are rejected and used for fuel, and not for board manufacturing since under-sized wafers, splinters, particles and fines utilize more resin and wax if they are not removed.

## 3.3 Board Fabrication

### 3.3.1 Dimensions and Wafer Conditioning

One size of waferboard, 16 x 24 x 7/16 inch (35.5 x 60.0 x 11.1 cm) was made. Three nominal board densities were produced at 36, 40 and 44 pound per cubic foot (pct), or at the specific gravity of 0.577, 0.641 and 0.705, based on oven dry weight. Boards were made in either a homogeneous one-layer or 3-layer construction. The homogeneous one-layer

boards of one thickness, were made with wafers which were treated under one steaming condition and were not screened. The three-layer boards were usually prepared with the smaller wafers being used at the core, while the larger wafers were used as the surface stock. Further variations of the 3-layer board included core wafers being steam treated at a higher intensity to provide an optimum curing level between the waferboard's face and core layers. In the later stage of the project, poplar fibres were used for core layer of waferboards. The fibres were produced from steam treated poplar chips which were defibrized and refined under pressure by a Sunds Defibrator. This type of defibration is widely used in the production of medium density fibreboard (MDF) and in the thermo-mechanical pulping industry. Acidic catalysts were also used in the wafers by treating them after steaming. Acidic catalysts were added to the steamed wafers in order to accelerate the curing time of the waferboard.

### 3.3.2 Press Conditions

Mats were formed by manual felting of the dried wafers. Nine different press conditions were selected with three platen temperatures of 210, 220, and 230 degree Celsius, and three press times of 8, 10, and 12 minutes. The pressing pressure was 300 psi (210 kPa). This pressing pressure was considerably less than the 400 to 500 psi normally used for conventional waferboard pressing. Even this relative low pressing pressure was found to produce too fast a closing rate for the steam treated wafers, resulting in a waferboard with highly densified surface layers and very low core densities; i.e. a waferboard having very high bending strength and very low internal bond. In the latter part of this project, the pressing pressure was further reduced to a range of 75 to 200

psi (50 kpa to 140 kpa), to counteract to the unique thermoplasticity of the steam treated wafers.

### 3.3.3 Board Testing

The fresh hot pressed waferboards were first conditioned at 20 degrees C. and 65% R.H. for one week then cut to provide 6 static bending test specimens. Three of these specimens were tested in the initial conditioned state while the other three specimens were boiled in water for 2 hours and tested in a wet condition. These bending tests provided modulus of rupture and modulus of elasticity (MOR and MOE) values, thickness swelling and permanent springback after boiling in addition to board thickness and density measurements. Two of the bending specimens tested in dry condition were further cut to supply six specimens for internal bond (IB) tests. In some cases, the bending specimens were also used for the measurement of linear expansion. All the test methods were in accordance with CSA standard methods (1).

## 4. RESULTS AND DISCUSSION

### 4.1. Effect of Steaming Condition

Steam treatment is the most vital part of this new process. Accordingly, finding the optimal combination of steaming temperature and steaming duration is essential in producing a boilproof waferboard with adequate physical properties. The two hour boiling test is the most stringent measurement of waferboard durability set forth by the CSA standard. Under or over steaming the wafers would result in a waferboard of inferior quality. Under steaming the wafers either by a low steaming

temperature and/or by insufficient steaming duration, or by the combination of both, would yield a relatively low content of carbohydrates and other decomposition products derived from the hemicellulose hydrolysis. The lower content of hydrolysate products would be insufficient to achieve a strong bond between the interfaces of wafers and to yield a waferboard of desirable quality. Over steaming of the wafers would generate an excess of bonding material which would result in a waferboard which was too rigid and possibly too brittle for commercial applications. Furthermore, over steaming would also damage the cellulose portion of the poplar wafers because of thermal decomposition and hydrolysis, ultimately resulting in a weak waferboard.

Figures 3, 4, 5, and 6 show the effect of the steaming condition on waferboard properties. As can be seen from these figures a consistent relationship between steaming conditions and physical properties of the waferboard appears to exist. Likewise, within the steaming temperature range of 210 to 250 degree Celsius and the steaming duration of 45 seconds to 12 minutes employed in this study, a very similar set of physical properties can be obtained by selecting an appropriate combination of steaming temperature and duration.

Among the specific physical properties examined, the bending strength and stiffness, in terms of MOR and MOE, were found to be the most sensitive with respect to the variety of steaming conditions employed. Over steaming always resulted in a waferboard with lower bending strength and stiffness, particularly those boards produced with higher steaming temperatures of 240 and 250 C. This negative effect was evident in the MOR of the waferboards made with wafers steamed at 250 degrees C. Bending strength decreased proportionally as the steaming duration increased from

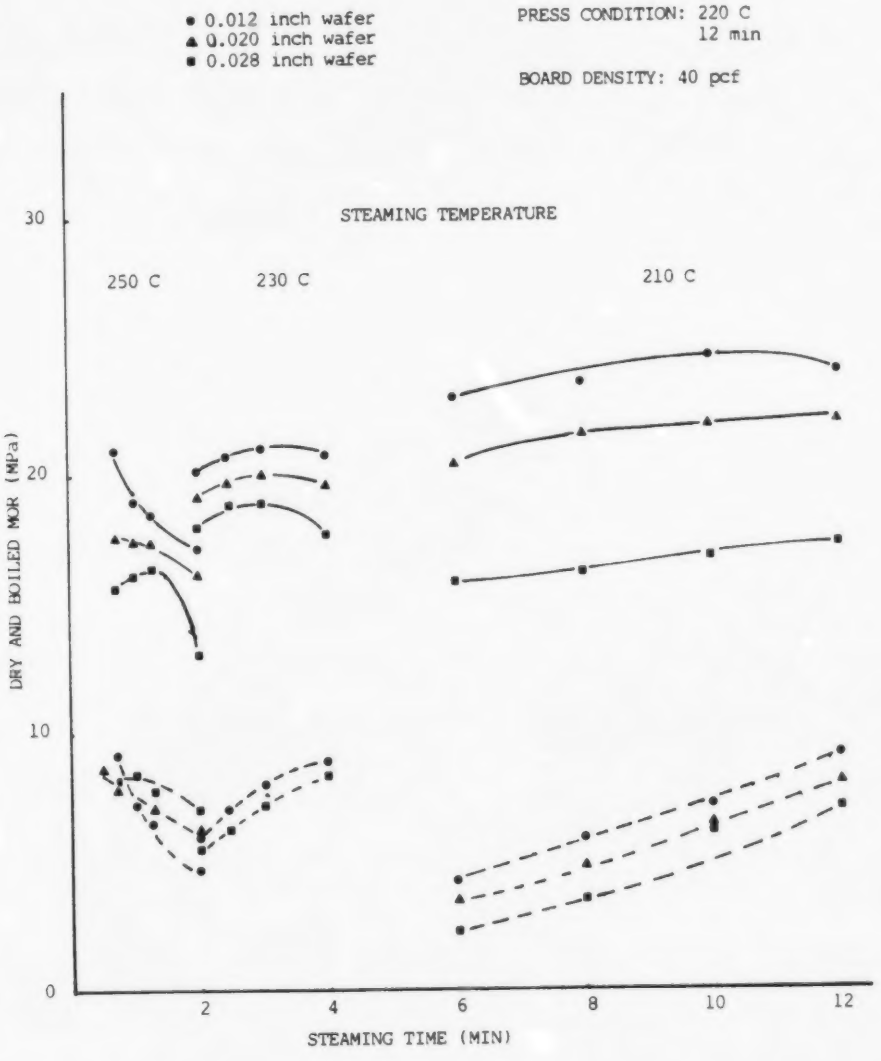



FIGURE 3. THE EFFECT OF STEAMING CONDITION ON MODULUS OF RUPTURE OF WAFERBOARDS

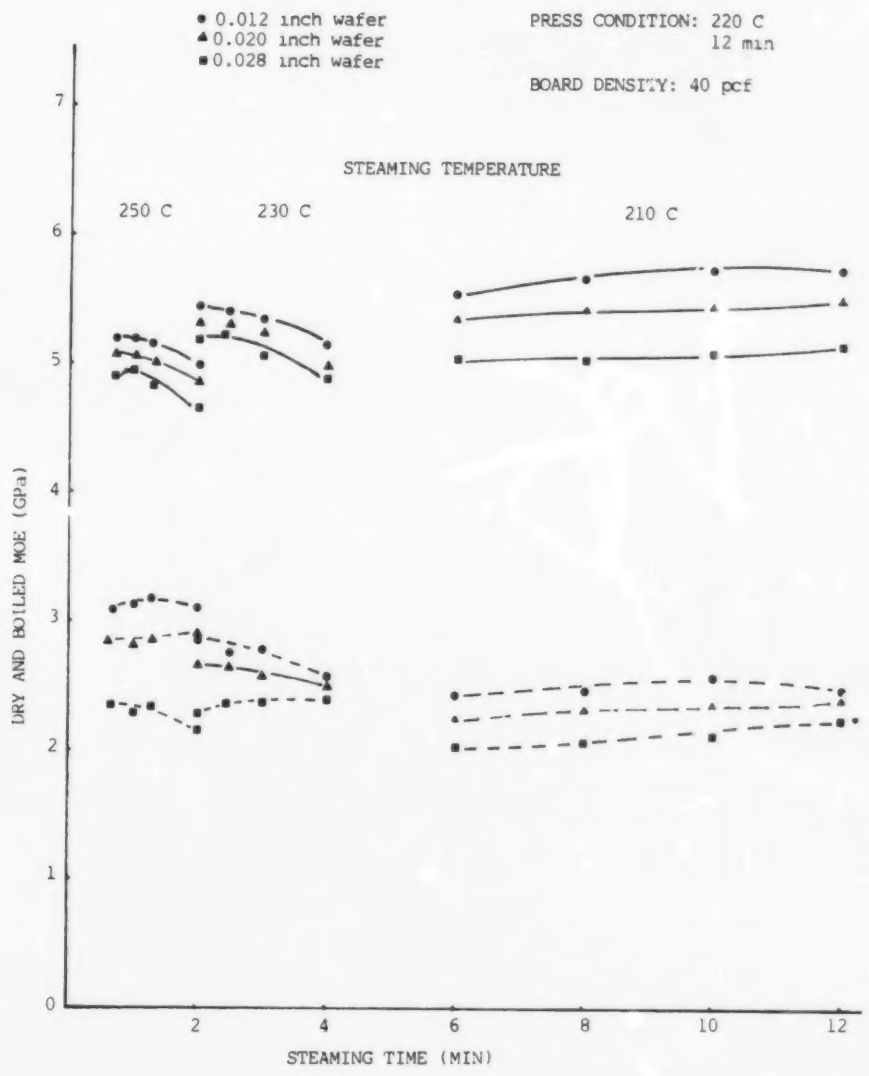



FIGURE 4. THE EFFECT OF STEAMING CONDITION ON MODULUS OF ELASTICITY OF WAFERBOARDS

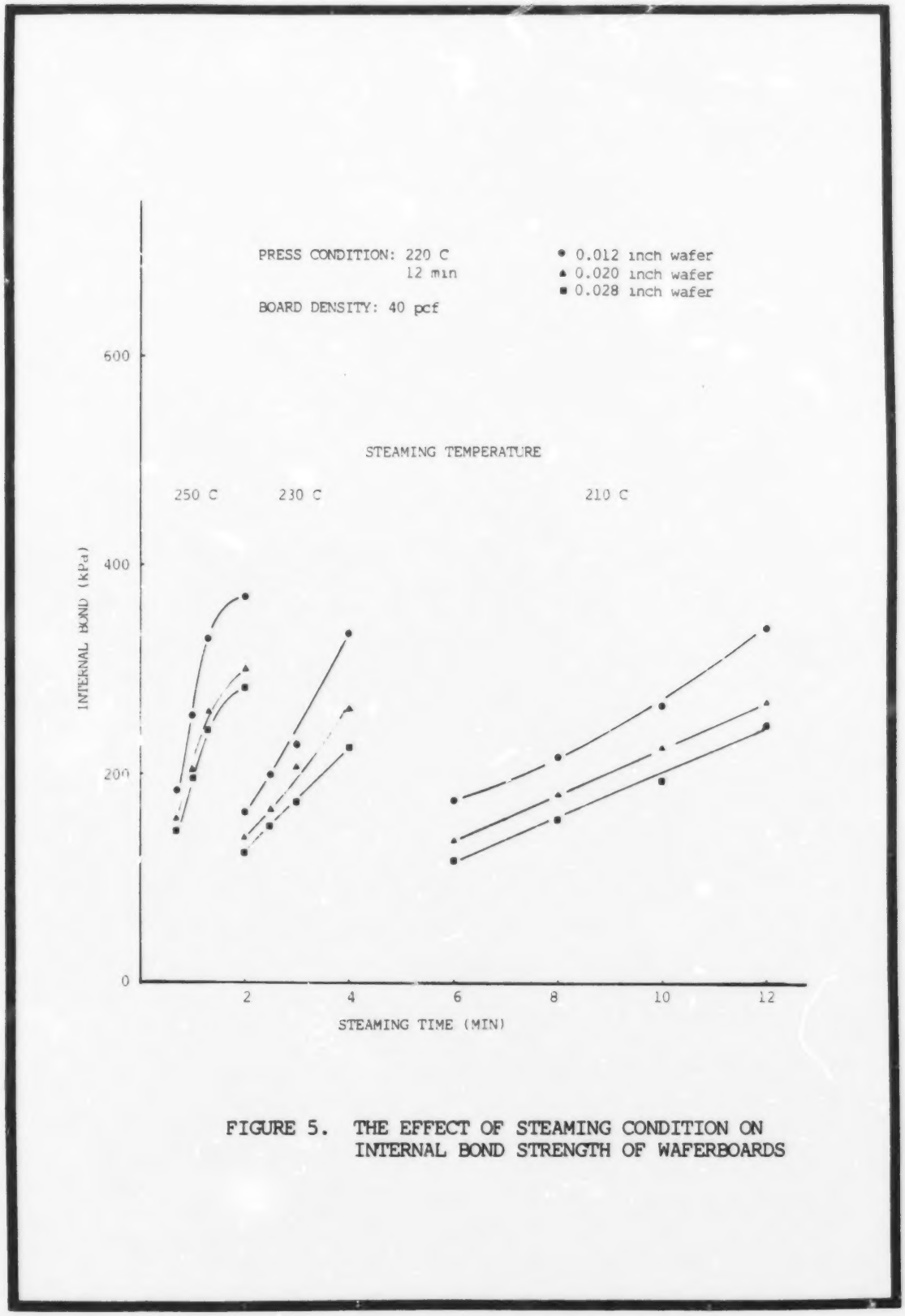



FIGURE 5. THE EFFECT OF STEAMING CONDITION ON INTERNAL BOND STRENGTH OF WAFERBOARDS

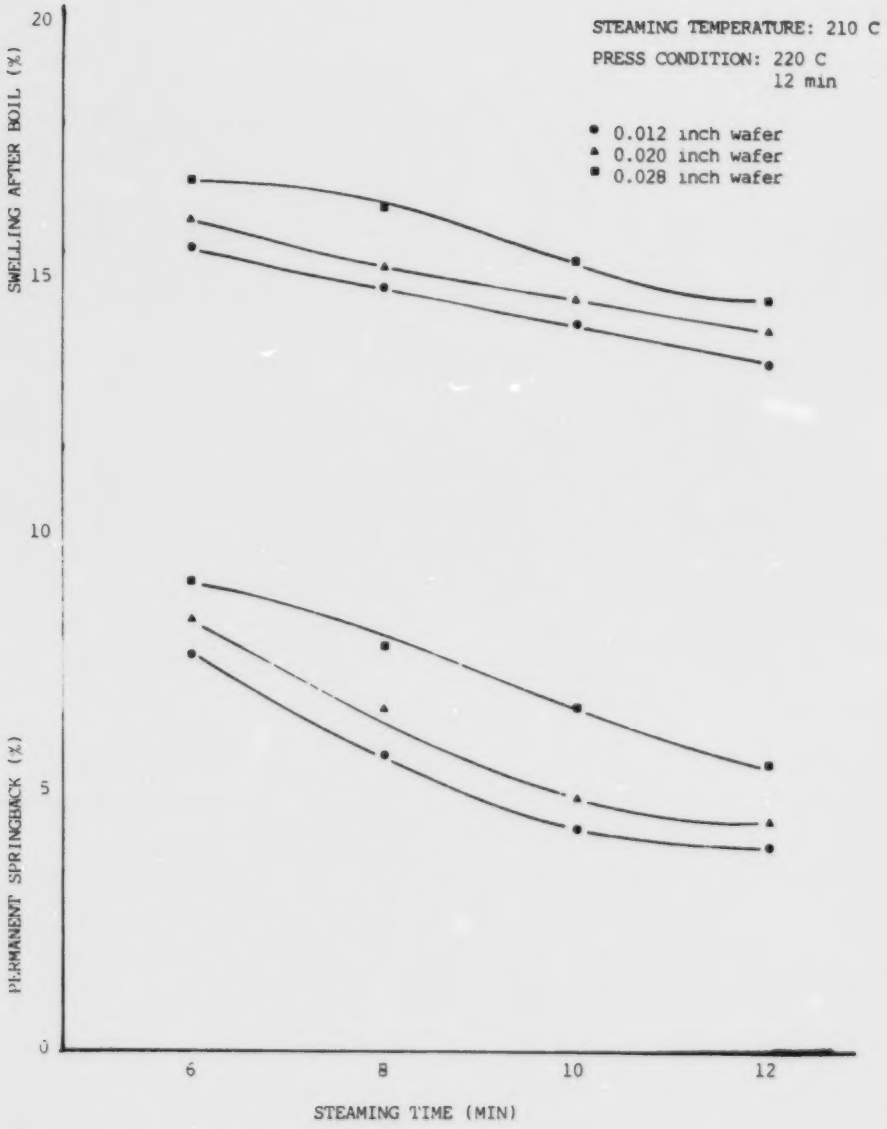



FIGURE 6. THE EFFECT OF STEAMING CONDITION ON DIMENSIONAL STABILITY OF WAFERBOARDS

45 seconds to 2 minutes. This influence was weaker in waferboards made with wafers steam treated at lower temperatures. Severe steaming conditions appeared to enhance internal bond strength and dimensional stability, in terms of thickness swelling and permanent springback. These improvements, in some cases, appeared to correspond in proportion to the lengthening of steam time or to the elevation of steam temperature.

A single steam treatment yields conflicting results (low in bending and high in internal bond) on the waferboard properties; however, this problem can be readily solved and turned into an advantage by manufacturing waferboards of a 3-layer construction, i.e., using mildly treated wafers for surfaces and intensively treated wafers for the core to produce a waferboard with very desirable property.

## 4.2. Effect of Wafer Thickness

Testing on auto-bonded waferboards made with various wafer thicknesses proved that the overall physical properties of these boards were improved as wafer thickness was reduced. Figures 7 and 8 demonstrate the close relationship between wafer thickness, bending strength and internal bond. Both MOR and MOE were increased by about 15 to 20% as wafer thickness was reduced from 0.028 to 0.012 inch. Similar physical improvements were also found in IB strength and dimensional stability. Thinner wafers provided a much tighter and smoother surface. A waferboard with smoother surfaces may be more appealing in certain applications.

One drawback of a thinner wafer is that it costs more to produce and would be more difficult to handle. It was discovered, for instance, that during the steam treatment some parts of the thinner wafers, usually in a small mass of wafers, were often under-steamed as may be seen by a

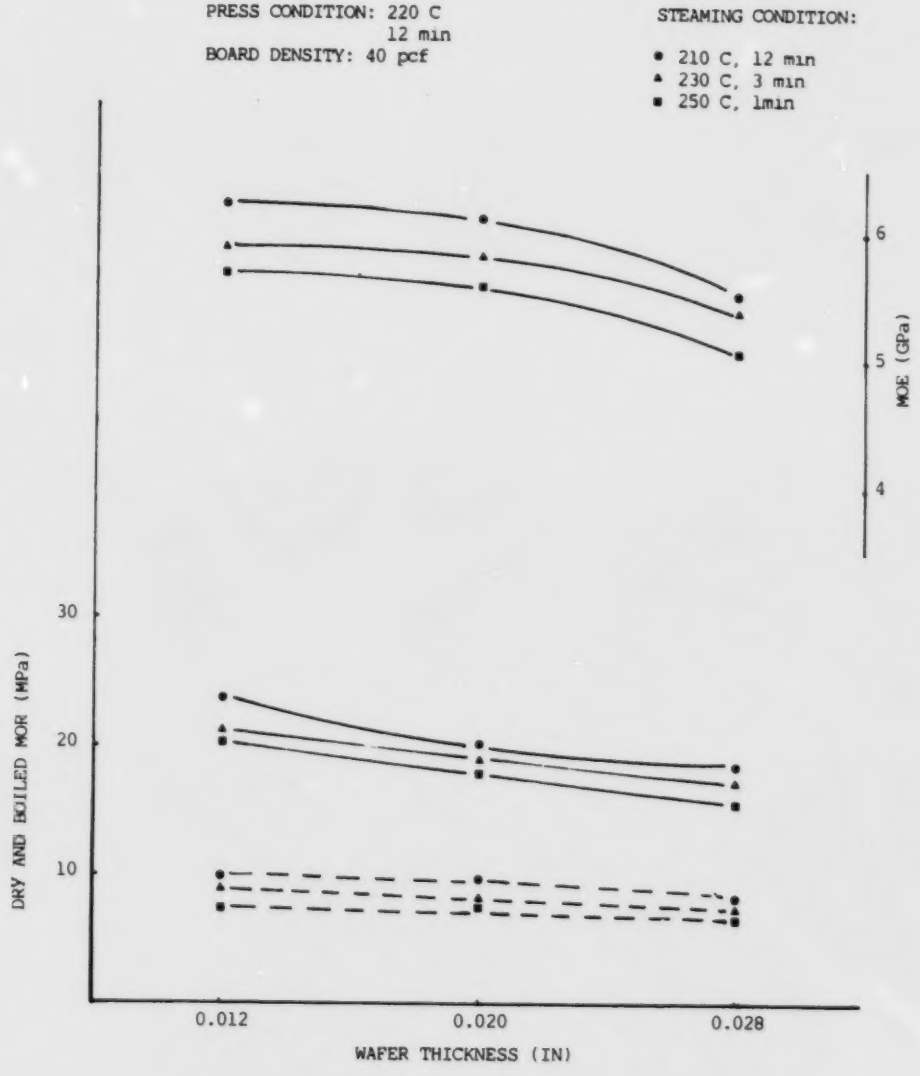
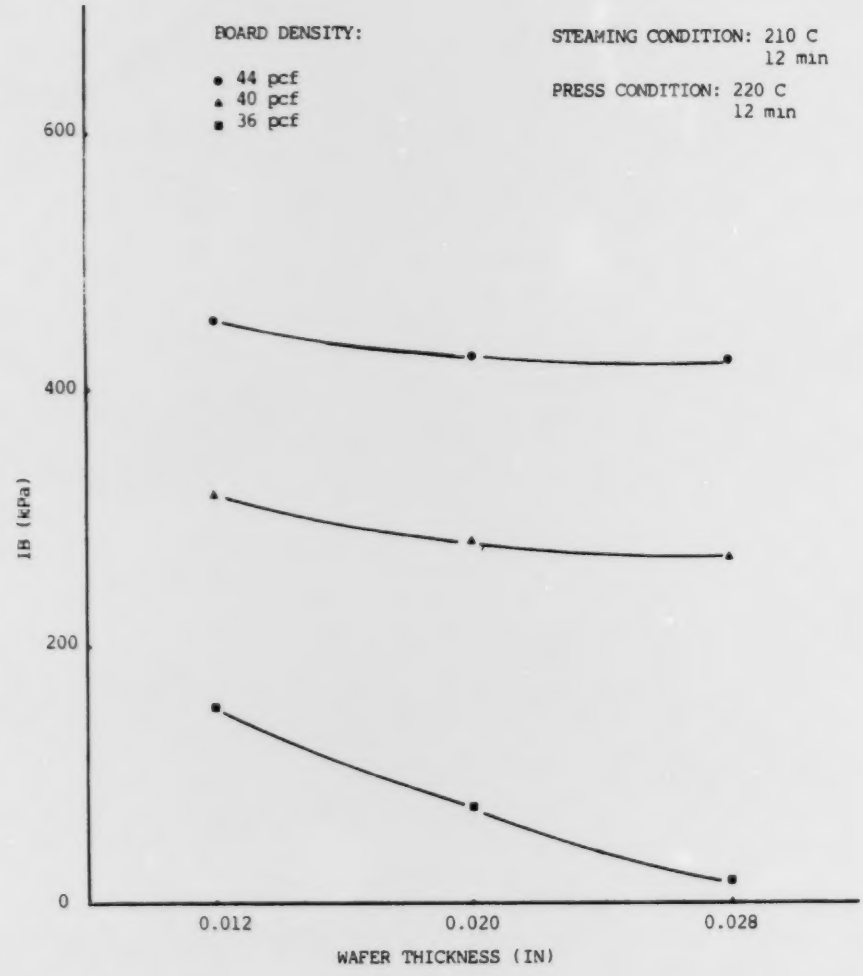



FIGURE 7. THE EFFECT OF WAFER THICKNESS ON MODULUS OF RUPTURE AND MODULUS OF ELASTICITY OF WAFERBOARDS




FIGURRE 8. THE EFFECT OF WAFER THICKNESS ON INTERNAL BOND STRENGTH OF WAFERBOARDS

light and pale spot on the wafers as shown in Figure 9. Sometimes this light coloured spot would extend to cover the whole wafer. This occurred more frequently in 0.012 inch wafers than in 0.020 inch wafers, and it seldom happened to the thicker wafers of 0.028 inch. It was interesting to note also that steam treatment at a higher temperature and shorter duration caused more under-steamed wafers than did milder treatment of lower temperatures combined with a longer steaming duration. It was also found that thinner wafers with a higher moisture content were more susceptible to under-steaming. The cause or causes of the under steaming is unclear at this moment; however, it is likely that the manner by which the wafers were packed into the stainless steel basket had a role in the under- steaming. Because thinner and wetter wafers easily formed layers and adhere into tightly packed bundles very similar to a pile of newspaper, it was more difficult for the steam to penetrate into the interfaces to heat the wafers uniformly. The presence of the under steamed wafers, even in a relatively small number, was not desirable from a viewpoint of board properties since the under-steamed wafers created a weak linkage between interface bonding. This weak bonding was particularly detrimental to the internal bond strength of waferboard of a homogeneous construction.

## 4.3 Effect of Press Condition

Higher platen temperatures and longer press times than commercial production of phenolic bonded waferboard were required to cure the new adhesive bond developed from the modified chemicals naturally occurring in the wafers. In this regard, the auto-bonded waferboards that had been cured with intensive press conditions of higher temperature and longer

FIGURE 9. THE UNDER-STEAMED WAFERS (A: GREEN WAFER B: PROPERLY STEAMED WAFER C: UNDER-STEAMED WAFER)

time were found to possess better overall board properties than those cured with a mild press condition. The combined effect of higher temperature and longer time was especially useful to improve the wet bending strength and dimensional stability. Figures 10 and 11 respectively show the relationships between pressing conditions and bending strength, internal bond and dimensional stability. Note that in Figure 10 the dry MOR appeared to maintain the same level, or even showed a tendency to weaken, as press time was lengthened. Wet bending strength, internal bond and dimensional stability were all improved proportionally to increases in press time.

## 4.4 Effect of Board Density

A waferboard with a higher density possessed superior physical properties overall. Bending strength, stiffness, and internal bond strength in particular were considerably enhanced as waferboard density increased. Figures 12 and 13 show the relationship between board density and specific properties. The dimensional stability, in terms of thickness swelling and permanent spring back, appeared to exhibit an inconsistent relationship to board density. There was also a close association between board density and wafer thickness. Of all the low density (36 pcf or sp. gr. 0.577) waferboards made in this project, thinner wafers of 0.012 and 0.020 inch were only able to yield a lower density waferboard with marginal strength properties and physical integrity. Waferboards of 36 pcf density made with 0.028 inch wafers were found to be too weak for testing, particularly with regard to IB strength. For instance, during the static bending test, centre core separation or shearing delamination took place in some samples. This problem was directly related to poor IB

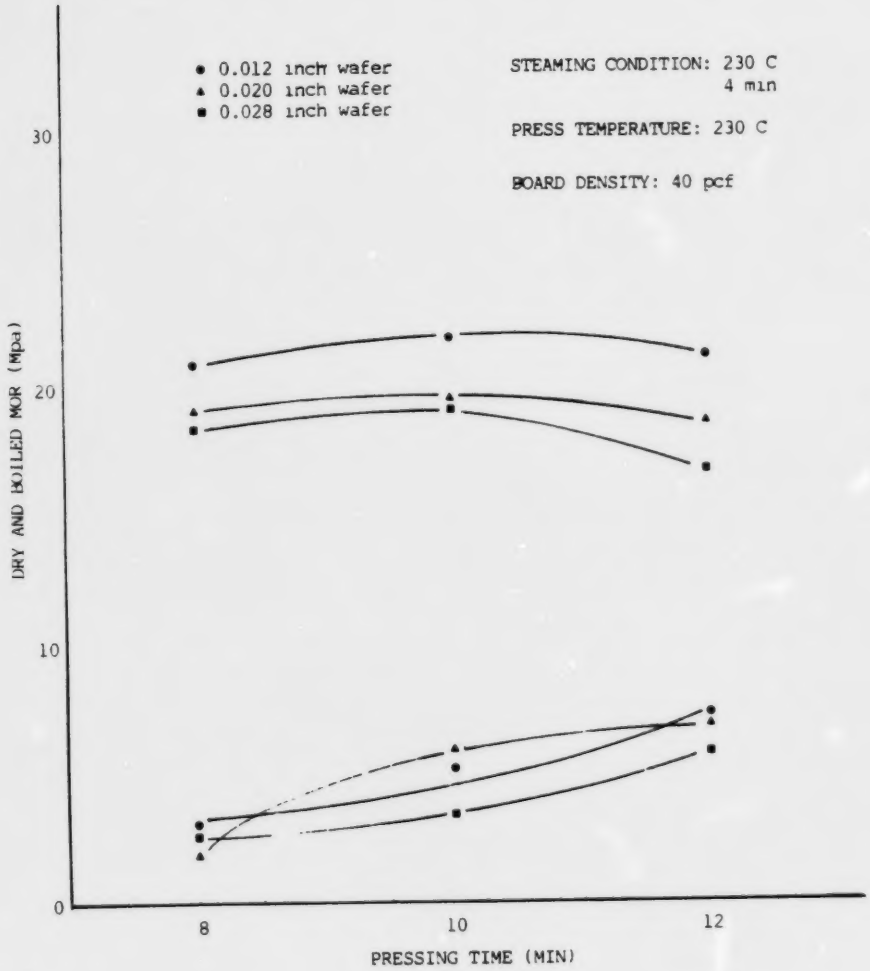



FIGURE 10. THE EFFECT OF PRESS CONDITION ON MODULUD OF RUPTURE OF WAFERBOARDS

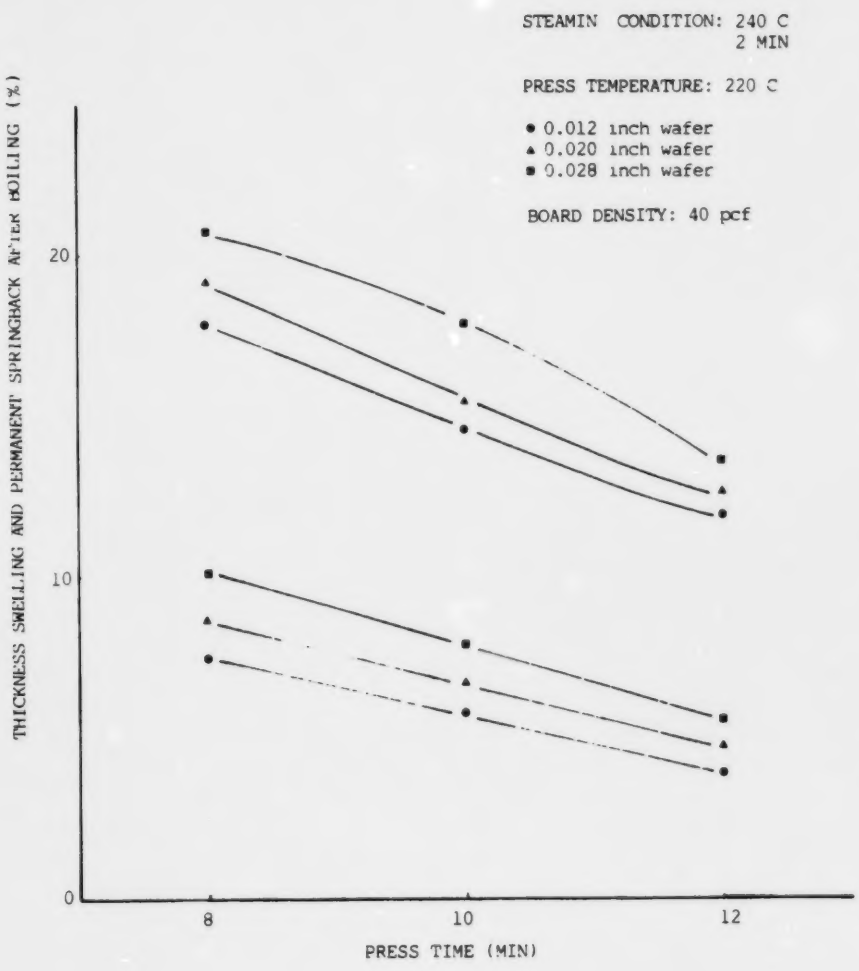



FIGURE 11. THE EFFECT OF PRESS CONDITION ON DIMENSIONAL STABILITY OF WAFERBOARDS

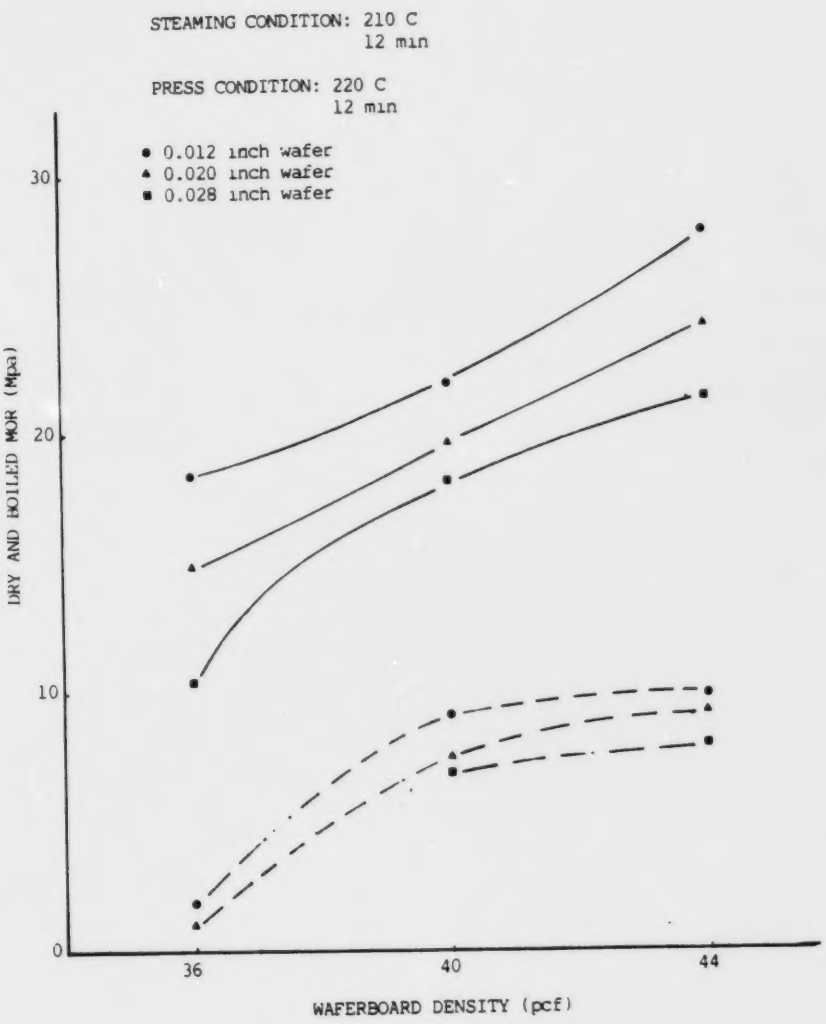



FIGURE 12. THE EFFECT OF DENSITY ON MODULUS OF RUPTURE OF WAFERBOARDS

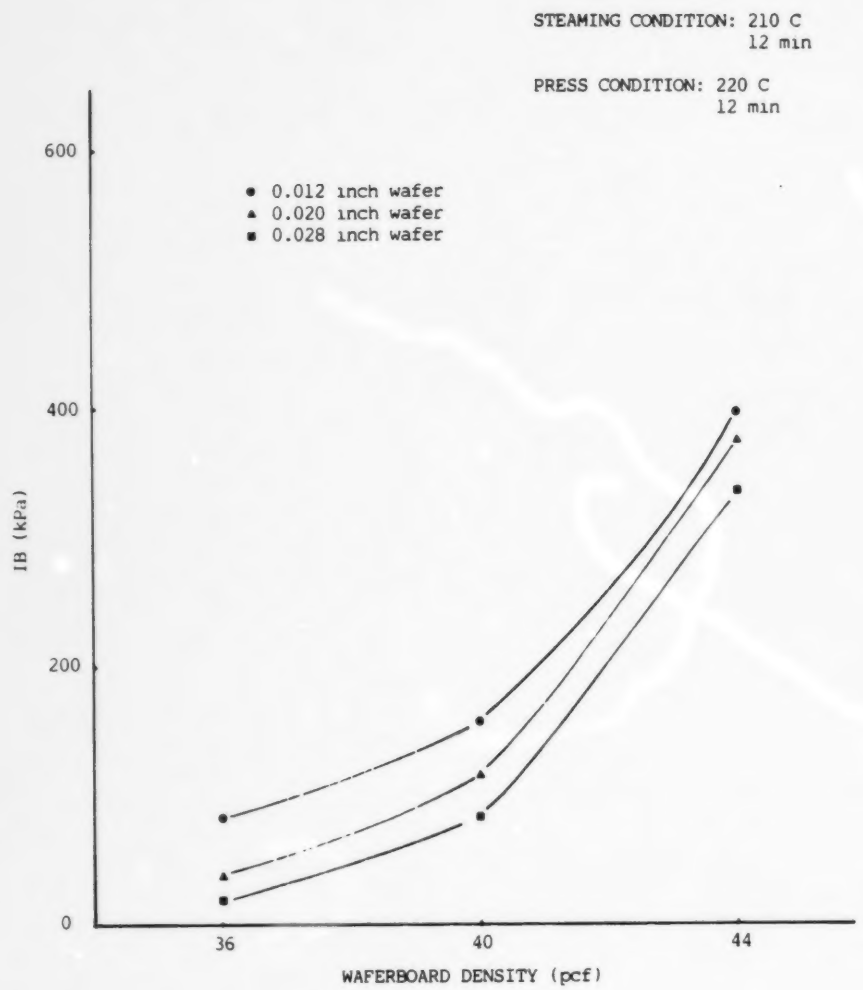



FIGURE 13. THE EFFECT OF DENSITY ON INTERNAL BOND STRENGTH OF WAFERBOARDS

strength. Based on this preliminary study, it was estimated that a 36 pcf waferboard made with 0.012 inch wafers could possess physical properties which were very similar to that of a 40 pcf waferboard made with 0.028 inch wafers.

At the beginning of the project, the old waferboard standard was used as reference (5). Since the introduction of the new waferboard standard in Canada in 1986, the target mechanical strength of auto-bonded waferboards had to be increased by 25%, accordingly, the density of the new waferboard had to be increased to meet these new standards.

## 4.5 Effect of Pressing Pressure on Board Quality

It was found that the steam treated wafers exhibited extra-ordinary plasticity during the hot pressing operation. It required less unit pressure during hot pressing. In the conventional practice it requires 400 to 600 psi of platen pressure to close the press with a closing time of one minute in order to produce a waferboard with high density surface layers which in turn, result in a high bending strength and a relatively low internal bonding strength.

In order to investigate the effect of the pressing pressure on overall waferboard properties, a series of waferboards were made with various pressing pressures from 125, 150, 175, and 200 psi. Two nominal thicknesses (012" and 020") of wafers, steam treated at 210 degrees C for 8, 10, and 12 minutes were used in this study. Press conditions consisted of one platen temperature of 220 degrees C, one press time of 10 minutes and 4 pressing pressures of 75, 100, 150 and 200 psi. A total of 24 waferboards of two different densities (40 and 44 pcf) were made with four different pressing pressures. The closing time varied from 85 to 190

seconds with a corresponding pressure from 200 to 75 psi. Under the same pressing conditions, mats made from thinner wafers of 0.012" were found to close slightly faster than the mats made with thicker wafers of 0.020". Figure 14 demonstrates the effect of pressing pressure on board properties.

## 4.6 Effect of Moisture Content of Green Wafers Before Steaming

It became very clear during the course of this project that the initial moisture content of the green wafers played an influential role in the bonding quality of the board produced. Since green wafers were cut from whole bolts, moisture variation within and between the individual bolts was of a considerable range. In order to investigate the effect of initial moisture content of green wafers on bonding quality, green wafers of 0.020 were controlled to three levels of moisture content before steaming. Wafers with a high moisture content of 100-120% were freshly cut from aspen bolts. One third of the wafers were steam treated immediately following waferizing. The second group of wafers was left to air dry to about 15 - 20% moisture content and were then steam treated. The third group of the green wafers was oven dried to 2 - 4% moisture content before steaming. Steaming conditions for these three groups consisted of 220 degrees C temperature with 4 of steaming times of 6, 8, 10, and 12 minutes.

Wafers containing different moisture contents showed different reactions to moisture changes after steaming. For wafers with a high initial moisture content, the steam treatment appeared to reduce the moisture content considerably. Air dried wafers with 15 - 20% moisture content did not undergo much change in moisture content after steaming.

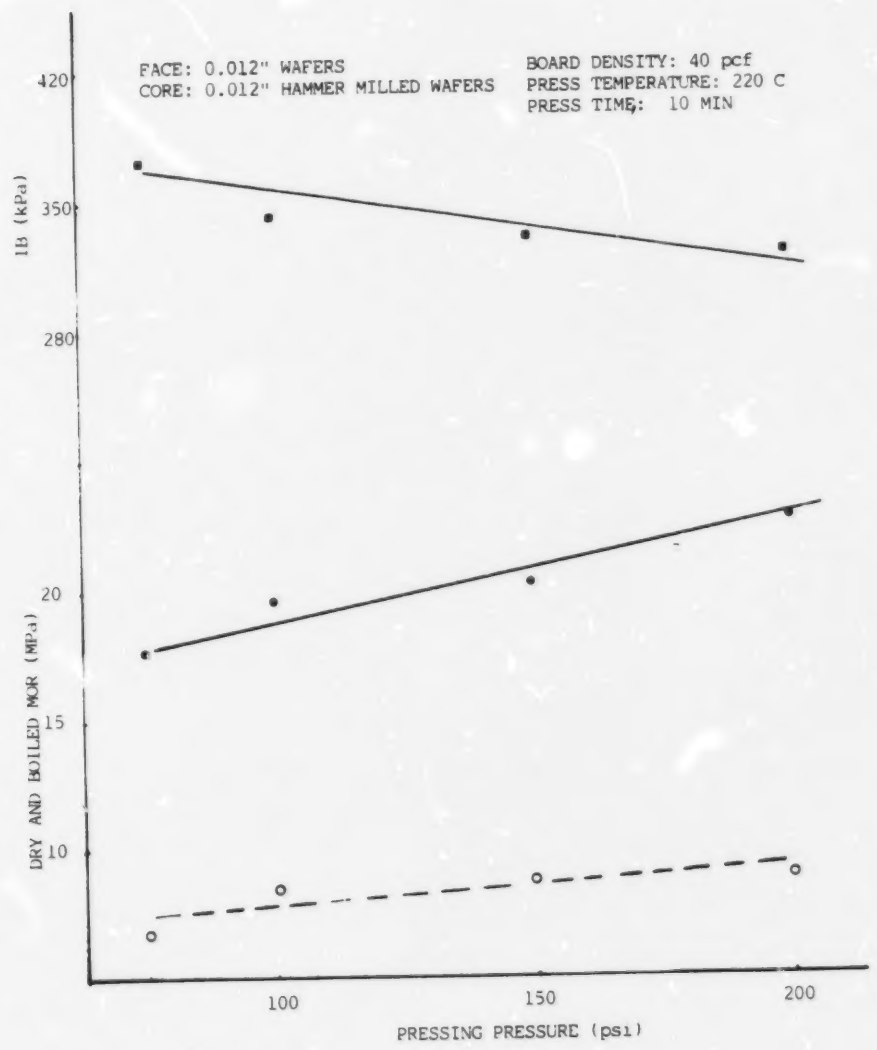



FIGURE 14. THE EFFECT OF PRESSING PRESSURE ON WAFERBOARD PROPERTY

The oven-dried wafers with a moisture content of 2 - 3% after the steam treatment gained moisture. Table (1) lists the moisture changes for wafers before and after steaming. All these groups of wafers were screened (1/4 inch screen) and separated into two fractions. The larger sized wafers were used for the face layer and the small sized wafers were oven dried to 2 - 3% moisture content for the core layer.

Nine waferboards (3 replications) of 40 pcf density were made from each group of wafers using one press temperature of 220 degrees C but with three different press times of 8, 10, and 12 minutes. Figure 15 shows the effect of the initial moisture content on waferboard properties which is represented by one steaming condition of 10 minutes. The poorer properties of waferboards made from low initial moisture content of 2 - 4% were the result of damaged wafers caused by pyrolysis during steaming, instead of hydrolysis in the case of wafers containing a sufficient moisture content.

In some extreme cases, the tapered ends of the steamed wafers were charred. This was more common when steam treating dry fibres at a high steam temperature for a long time.

## 4.7 Large Vessel vs. Steam Press Chamber

The specially designed and manufactured high pressure vessel (10 inch diameter and 36 inch length) was used extensively for steam treating the wafers. It was found however, that due to poor pressure vessel insulation and the batch operation system, a fair amount of water soluble material, mainly carbohydrates, was lost from the wafers as condensed vapour during the steaming period. In a similar setup of a steam press in which the steam chamber was the heated press platen, it was found that the

TABLE 1

MOISTURE CHANGE BEFORE AND AFTER STEAMING

| STEAM CONDITION | GREEN WAFERS BEFORE STEAMING | M.C. (O.D. WAFER WEIGHT WET WAFERS AFTER STEAMING | INCREASE OR DECREASE |
|---|---|---|---|
| 250 Deg C/3/4 min | 100-120 | 83-102 | DECREASE |
| 1 min | 100-120 | 77-92 | DECREASE |
| 1 3/4 min | 100-120 | 72-90 | DECREASE |
| 2 min | 100-120 | 68-88 | DECREASE |
| 230 Deg C/2 min | 15-20 | 18-26 | INCREASE |
| 2 1/2 min | 15-20 | 17-24 | INCREASE |
| 3 min | 15-20 | 21-23 | INCREASE |
| 4 min | 15-20 | 22-27 | INCREASE |
| 230 Deg C/ 2 min | 2-3 | 32-46 | INCREASE |
| 2 1/2 min | 2-3 | 28-43 | INCREASE |
| 3 min | 2-3 | 28-45 | INCREASE |
| 4 min | 2-3 | 39-55 | INCREASE |

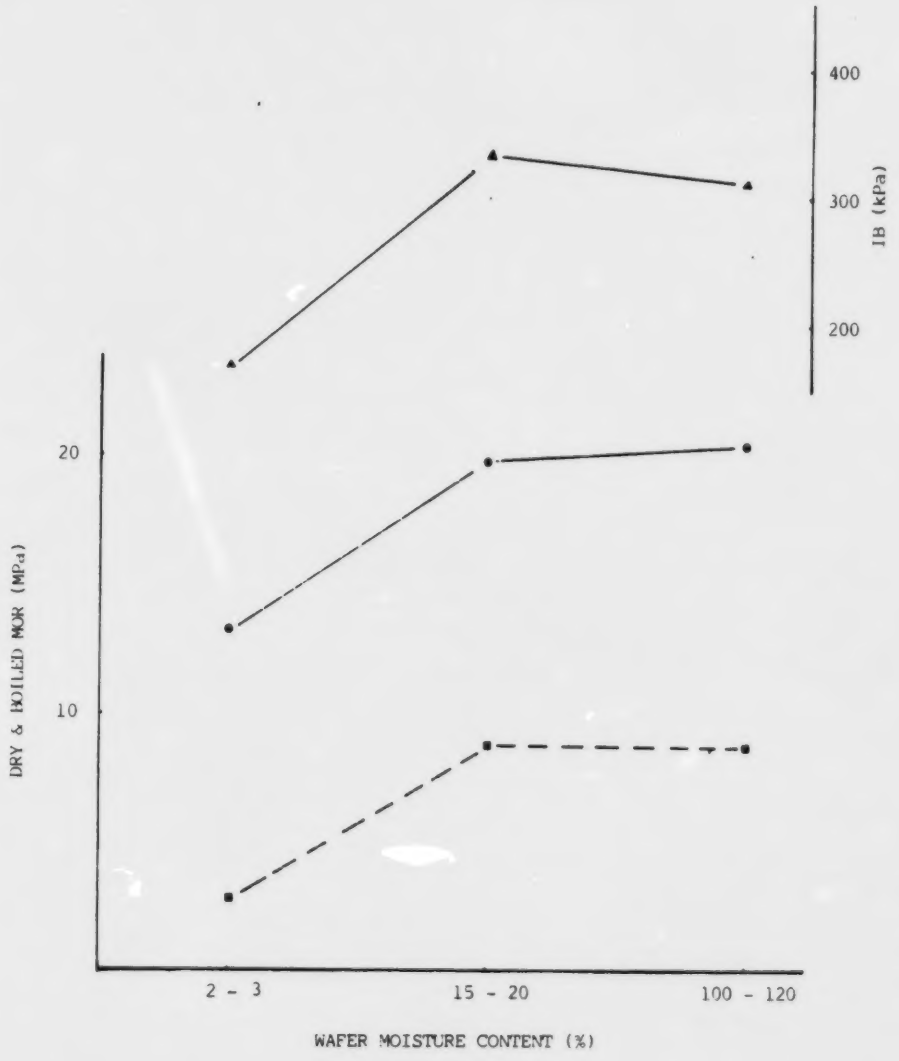



FIGURE 15. THE EFFECT OF MOISTURE CONTENT OF WAFERS BEFORE STEAMING ON BOARD PROPERTY

wafers lost less water solubles as a result of vapour condensation. Wafers treated in the steam press chamber always contained more water solubles. Chemical analysis by TAPPI method T-0122 revealed a difference in water soluble solids of 3 - 4 %, based on O.D. wafers, between wafers treated separately in the two different treating vessels (vessel vs. chamber) but under the same treating conditions (steam temperature 210 degree C and steaming time 6,8,10 and 12 minutes) (13). Table 2 lists the difference in weight retention of the water soluble material of wafers treated by two different pressure vessels.

The loss of the water solubles or the low molecular carbohydrates from steamed wafers meant the loss of bonding agent. It is expected, therefore, that wafers which lost more water solubles would yield a waferboard of poorer quality. Waferboards made with 0.012" wafers treated with the large pressure vessel and the steam press chamber respectively, using identical pressing conditions confirmed the differences in board properties.

In general, waferboards made with wafers treated in the steam press chamber were superior in mechanical strength to waferboards made with wafers treated in the big pressure vessel, thereby confirming the detrimental effect of the loss of valuable water solubles from the wafers. Figures 16 shows the difference in both dry and boiled bending strength and internal bond of waferboards made from wafers which were steam treated in the two different pressure treating vessels as listed in Table 2. This difference was in the range of 5 to 29%, in terms of physical properties, with the MOE being the least and the IB the most affected by the loss (3 - 4%) of water solubles in the wafers.

TABLE 2

WATER SOLUBLES IN STEAMED WAFERS

| STEAM CONDITION | BIG VESSEL (% solids based on O.D. wafer Weight) | STEAM PRESSURE CHAMBER (% solids based on O.D. wafer Weight) |
|---|---|---|
| 210 deg C/6 min | 13.6 | 17.2 |
| 210 Deg C/8 min | 15.6 | 19.2 |
| 210 Deg C/10 min | 19.3 | 23.5 |
| 210 Deg C/12 min | 20.1 | 23.7 |

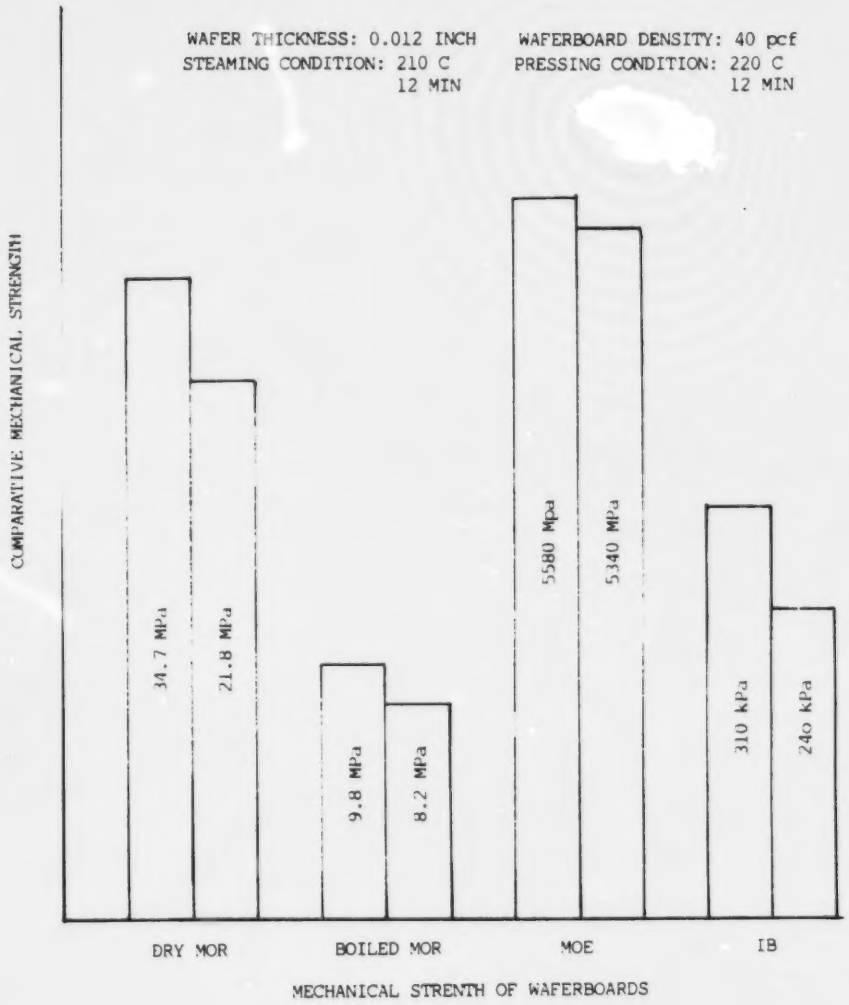



FIGURE 16. THE EFFECT OF DIFFERENT TREATING VESSELS ON WAFERBOARD PROPERTY

## 4.8 Effect of Wafer Size

It was anticipated that it would be difficult to obtain a uniform steam treatment for large sized wafers (ie. large surface area). It was noted that large sized wafers were often under-steamed and resulted in a light colour on the wafer surface. Furthermore, these spots occurred more often on thinner wafers. These under-steamed spots were caused by the overlap of wafers which contained a high moisture content. Thinner wafers tended to stick together inside the high pressure vessel making it difficult for the steam to cover and penetrate the whole wafer surface. Figure 9 shows the under-steamed wafers with light colour spots.

These under steamed spots did not generate enough water soluble material for bonding and they always represented a potentially weak linkage in the waferboard matrix, resulting in poor mechanical properties. These weak links were particularly detrimental to the internal bond strength (tensile strength perpendicular to surface). In order to minimize the adverse effect of these spotty wafers, a series of studies was carried out to determine the effect of wafer size on board properties.

Wafers of 0.012" thickness were steam treated at 210 C for twelve minutes, air dried to a moisture content of about 5%, and divided into three equal parts. The first part of the wafers was made into a waferboard of one-layer homogeneous construction. The second part of the wafers were put through a hammer mill with a 1/4 inch screen and then made into boards of one-layer homogenous construction. The remaining one third of the wafers were screened (1/4 inch size) to separate them into two sized fractions. The larger fraction was used for face wafers and the small sized fraction was used for the core of a 3-layer waferboard.

Figure 17 shows the relative sizes of the wafers used in this part of the project. All of the homogeneous and 3-layer waferboards were pressed under identical conditions with the density of 40 pcf. Test results indicated that waferboards made from hammer milled stock in general possessed better strength properties. The increase in internal bond strength was significant. Table 3 shows the strength properties of waferboards made of wafers in three different sizes and constructions.

The improvement of the waferboards made from the small sized hammer milled wafers is mainly due to the increased uniformity of the mat and the randomization and re-distribution of the under-steamed wafers.

## 4.9 Effect of Wafer Length

In commercial production, two different lengths of wafer (1 1/2 and 3 inch) have been utilized to produce waferboard. In this study 1 1/2 and 3 inch wafers of 0.020" thickness were made from bolts randomly selected from five poplar logs. The wafers were air dried to a moisture content of about 20 - 30% before being subjected to the steam treatment (240 C, 1 min).

A set of 12 waferboards (of homogeneous construction) were made at two different density levels (40 and 42 pcf) but were pressed under identical conditions. The MOR and MOE for waferboards made with longer wafers were slightly higher but not statistically significant. Internal bond strength; however, for boards made from longer wafers appeared to suffer. This was mainly due to a less uniform core formation because of a small numbers of large sized wafers.

TABLE 3

WAFERBOARD MADE FROM DIFFERENT SIZE WAFERS

Wafer Size 0.020 inch, Steam Condition 230/3 min
Press Condition 220 deg C/12 min

| WAFER SIZE Construction | DENSITY | MOR (MPa) DRY | MOR (MPa) BOILED | MOE (MPa) DRY | MOE (MPa) BOILED | IB (kPa) | LINEAR EXPANSION (50%-90%RH) |
|---|---|---|---|---|---|---|---|
| Full Size homo wafer | 39.8 | 19.3 | 7.3 | 4872 | 2663 | 232 | 0.20 |
| | 42.2 | 20.7 | 7.9 | 5164 | 2872 | 256 | 0 19 |
| | 43.9 | 22.2 | 8.7 | 5872 | 3126 | 330 | 0.21 |
| Full Size Wafer Hammer Milled Wafer Core 3-Layer board | 40.2 | 20.2 | 8.6 | 5217 | 2827 | 330 | 0.20 |
| | 42.4 | 22.4 | 9.7 | 5774 | 3128 | 372 | 0.18 |
| | 44.3 | 24.6 | 10.8 | 6015 | 3230 | 408 | 0.19 |
| All Hammer Milled Wafer Homogeneous | 39.8 | 20.3 | 8.8 | 4996 | 2836 | 302 | 0.21 |
| | 41.8 | 21.7 | 9.5 | 5478 | 3047 | 346 | 0.22 |
| | 44.6 | 23.8 | 11.2 | 5977 | 3182 | 388 | 0.21 |
| CSA-Requirement | - | 17.2 | 8.6 | 3500 | - | 350 | |

FIGURE 17. STEAMED WAFERS OF VARIOUS SIZES

## 4.10 Waferboard with Fibre Core

Green poplar chips were steamed treated with steam in a range of temperatures and times in a manner similar to wafers with the additional step of refining the steamed chips into fibres by a Sunds defibrator at the Pulp and Paper Research Centre (PPRC), University of Quebec in Trois Rivieres. Poplar chips were first steamed at 240 degrees C. for 45, 60, and 90 seconds respectively. The steam treated chips were then run through a Sunds defibrator under a steam pressure of 120 psi. This is the same defibrating process used to reduce wood chips into fibres for the manufacture of medium density fibreboard or for the production of thermo-mechanical pulp. The wet fibres which contained about 120 -180% moisture content, were first air dried, then oven drying to a moisture content of 2-3% for use as waferboard core stock. All wafers were 0.012 inch in thickness, steamed at 220 degrees C. for 8 minutes and air dried to 4-6% moisture content. A 3-layer waferboard was fabricated with a construction of 50% by weight of face wafers and 50% by weight of core fibres. A total of seventy-two 3-layerboards were made with one pressing condition (220 degrees C. for 10 minutes). Test results are summarized in Table 4. The bending strength for all wafer-fibreboards was very close to that of waferboards which were made with 100% wafers and of homogeneous one-layer or 3-layer construction. But the internal bond strength was higher for the waferboards with fibre cores. Of the three core fibres, the longest steaming time of 90 seconds at 240 degrees C. gave the highest internal bond strength. The IB strength increased in proportion to the steaming time from 30 to 90 seconds.

TABLE 4

3-LAYER WAFERBOARD WITH FIBRE CORE

(Face Wafer: 0.012 inch, 240 deg C/1 1/2 min)

| CORE FIBRE Steam Cond. | DENSITY (pcf) | MOR (MPa) DRY | MOR (MPa) BOILED | MOE (MPa) DRY | MOE (MPa) BOILED | IB (kPa) | LINEAR EXPANSION (50%-90%RH) |
|---|---|---|---|---|---|---|---|
| 230 Deg C 1/2min | 40.2 | 19.2 | 4.2 | 5119 | 2677 | 135 | 0.19 |
| | 40.2 | 20.2 | 5.5 | 5322 | 2836 | 260 | 0.19 |
| | 44.4 | 22.7 | 6.1 | 5889 | 3210 | 370 | 0.20 |
| 250 Deg C 1 Min | 40.4 | 18.7 | 6.6 | 5036 | 2725 | 225 | 0.21 |
| | 41.8 | 19.2 | 7.4 | 5471 | 2927 | 285 | 0.20 |
| | 44.2 | 22.4 | 8.2 | 6213 | 3236 | 302 | 0.21 |
| 250 Deg C 1 1/2 min | 40.6 | 20.6 | 8.3 | 5872 | 3128 | 312 | 0.21 |
| | 42.5 | 22.6 | 9.6 | 6125 | 3224 | 367 | 0.21 |
| | 43.9 | 24.7 | 11.2 | 6357 | 3321 | 392 | 0.21 |
| CSA-Requirement | - | 17.2 | 8.6 | 3500 | - | 350 | |

## 4.11 Effect of Acidic Catalyst

The curing rate of auto-bonded waferboard was much slower than the curing rate of phenolic bonded waferboards - approximately 100% longer. As a result, longer press times and higher press temperatures were required to achieve satisfactory bond properties, particularly with regard to the wet strength or the resistance to boiling. In an attempt to increase the curing rate or to shorten the press time for the auto-bonding process, an acidic catalyst, ammonia chloride, was added to the steamed wafers and fibres core stock before mat felting. The catalyst was first dissolved in water and then sprayed onto the wafers and fibres. Four levels of catalyst were selected for application to the core stocks of wafers or fibres. They were based on solid weight of O.D.core stocks at 0, 0.25, 0.5 and 1.0% levels. It was observed that the liquid spray of the catalyst was not compatible with wafers as the relatively small amount of liquid catalyst was insufficient to give a uniform coverage to the wafers. On the other hand, spraying on the fibre core material encountered no problems. A total of 72 waferboards, including 36 homogeneous waferboards and 36 3-layer boards of wafer-fibre-wafer construction, were fabricated and tested. Test results are listed in Table 5. In general, the addition of an acidic catalyst sped up the curing rate and shortened the press time for auto-bonded waferboards of homogeneous or 3-layer construction by 20 to 30%. The improvement in time is directly related to the amount of catalyst used. It also appeared that a catalyst was more effective in the 3-layer waferboards with fibre core than with the homogeneous boards. This may be attributed to the better coverage of liquid catalyst in fibres. In addition, the moisture movement in the 3-layer board was always faster than the homogeneous board made

TABLE 5

EFFECT OF ACIDIC CATALYST ON PRESS TIME

| ADDITION OF NH4Cl (%) | PRESS TIME IN MINUTES AT 220 DEG C | MOR (mPa) HOMO WAFERS DRY | HOMO WAFERS BOILED | FIBRE CORE DRY | FIBRE CORE BOILED |
|---|---|---|---|---|---|
| 0.0 | 10 min | 20.4 | 8.5 | 21.5 | 9.2 |
| | 8 min | 1.6 | 0.0 | 22.3 | 4.6 |
| | 6 min | 20.2 | 0.0 | 23.7 | 3.3 |
| 0.25 | 10 min | 21.8 | 8.8 | 20.5 | 9.6 |
| | 8 min | 19.2 | 7.2 | 21.3 | 8.9 |
| | 6 min | 17.8 | 3.2 | 18.9 | 6.2 |
| 0.50 | 10 min | 18.6 | 9.2 | 21.2 | 10.2 |
| | min | 19.2 | 8.7 | 19.7 | 9.8 |
| | 6 min | 20.2 | 5.7 | 19.4 | 7.2 |
| 1.00 | 10 min | 19.3 | 10.2 | 20.4 | 11.2 |
| | 8 min | 21.5 | 9.3 | 22.6 | 9.7 |
| | 6 min | 20.2 | 7.5 | 21.7 | 8.2 |

with 100% wafers. Because the large sized wafers are interlaced with one another, they tend to block the moisture migration from core to surfaces, therefore slowing down the curing rate.

## 4.12 Morphology of the Steamed Wafers

Steam treatment caused wafers to change in both chemical and physical nature. Physically, steamed wafers after drying became slightly thinner and relatively weaker, a bit brittle and less hygroscopic. Furthermore, steamed wafers tended to warp or curl. This phenomenon was particularly evident in the thinner wafers. Figure 18 shows the warping of wafers of different thicknesses after being subjected to the same steam treatment. The frequency of warping was also intensified by the size of the wafer, i.e. larger wafers had a higher tendency to warp than did small wafers. It appeared that warping was caused by the uneven thermal contraction of the steamed wafers during drying. This undesirable warping caused difficulty in felting a uniform mat and resulted in a bulky mat. Thin and large wafers of 0.012 inch thickness usually yielded a considerably bulky mat in comparison to mats made of thicker wafers of 0.020 and 0.028 inch and treated under the same steaming conditions.

## 4.13 Weight Loss Due to Steam Treatment

There was a material loss as a result of steam treating the wafers. This was anticipated because of the thermal degradation and decomposition of lignocellulosic material by autohydrolysis. The loss of weight was mainly due to the escape of volatile and gaseous products generated from the decomposition and hydrolysis of hemicellulose, lignin and extractives. To a lesser extent, there also was a loss of water

FIGURE 18. WARPING WAFERS

solubles in the range of 1 - 2%, resulting from the drainage of steam condensate during the steam treatment. This combined weight loss, based on oven dry weight of wafers, was in the range of 3 to 8%, depending mainly upon the severity of steam treatment and to a lesser degree, on the initial moisture content and thickness of the wafers. Figure 19 shows the linear relationship between weight loss and the intensity of the steam treatment. The weight loss found in this study was lower than the range reported for similar work involving the steam explosion of poplar wood as a pretreatment for liquid fuel production and steam pretreatment of mill residue for production of waterproof fuel pellets (7 and 8). The difference may be attributed to the different steaming treatment method in that the previous work involved an explosive discharge of treated material in comparison to the present project where treated material was released without the violent explosive discharge.

The loss of mass due to steam treatment appears to be an intrinsic part of the auto-bonding process. One must remember that the major chemical synthesis in the petro- and carbo-chemical industries starts with chemicals generally lacking in oxygen or having exclusively carbon and hydrogen atoms; thus the yield of these processes is theoretically excellent and in practice, desirable. Whereas with oxygen rich carbohydrates, reactions generally lead to loss in weight with the production of $CO_2$ and/or $H_2O$; hence poor theoretical yields which are further reduced in practical applications. It is difficult at present to assess its effect in terms of bonding quality; however, from a manufacturing point of view, it is undesirable to lose material in a process.

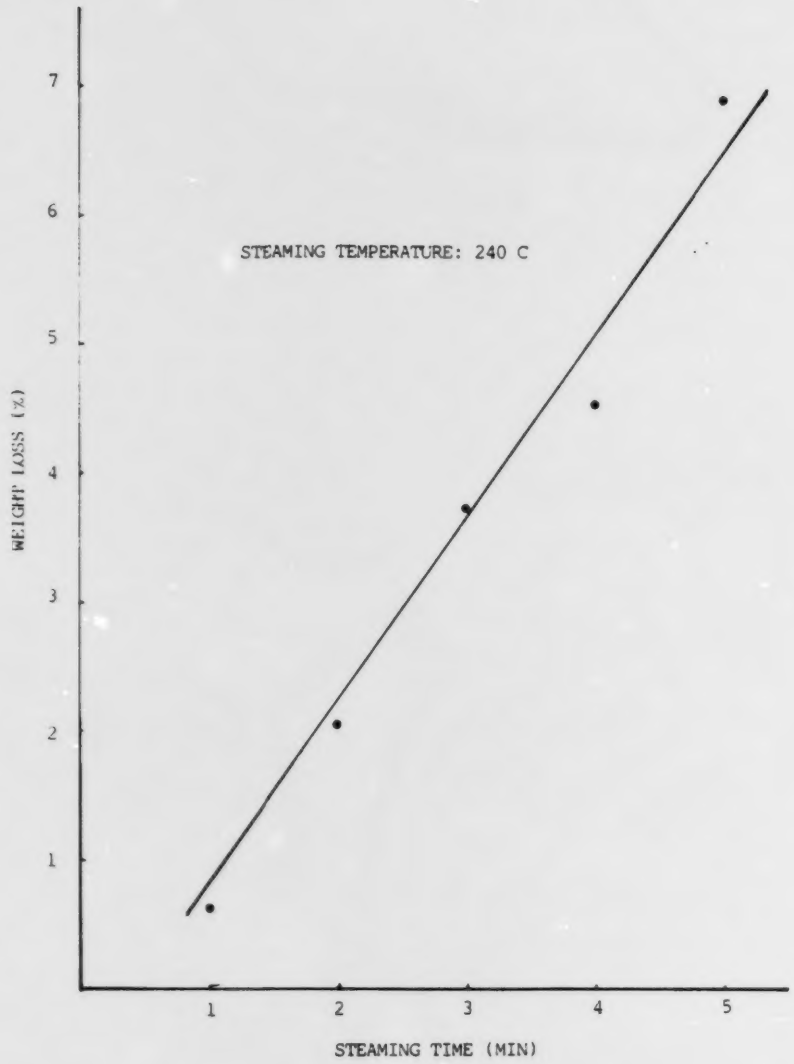



FIGURE 19. WEIGHT LOSS DUE TO STEAMING

## 4.14 Weight Loss Due to Hot Pressing

As expected, there was also a mass loss due to the chemical transformation of the water solubles in the wafers during hot pressing. The weight loss, based on oven dry weight of wafers, was in the range of 2 - 3%. This weight loss was very closely related to the severity of the steaming condition to which wafers were subjected. To a lesser degree, this weight loss was also influenced by the press conditions. Higher platen temperatures and/or longer press times always caused a higher loss of more mass during pressing.

It is well known to wood chemists that, on acid hydrolysis, hardwood hemicellulose yields xylose, which subsequently loses 3 water molecules to form furfural or its intermediates during hot pressing under high temperature and pressure. In addition, there is a trace of organic acids such as acetic and formic acids formed during hydrolysis of hemicellulose during the steam treatment. Steam vapour collected during board pressing indicated the presence of highly acidic substances. This may be related to the fact that the pH level of waferboards produced was found to increase as press time lengthened. The loss of acidic substances appears to have a positive effect on board properties by increasing the long term durability of the bond.

## 4.15 Acidity of Steamed Wafers and Waferboard

During the steam treatment, poplar wafers underwent decomposition and hydrolysis. Organic acids such as acetic or formic acid were generated during the steam treatment and resulted in wafers of an acidic nature. The acidity of the steam treated wafers was mainly determined by the intensity of the treatment; higher steam temperature or longer

treating periods always increased the acidity of the treated wafers. Figure 20 shows the relationship between the degree of steam treatment and the acidity of the wafers and the resultant waferboards. In comparison to untreated wafers (pH 5.6), the steamed wafers were relatively acidic. Although organic acids are weak in nature, the amount of acids may cause concern with regard to the long term durability of the waferboard made with these acidic wafers.

Further investigation indicated that the acidity of wafers decreased after they were processed into panels. It was believed that the acids in the wafers were consumed during the hot pressing through a catalytic or transformation reaction. The reduction of the acidity was also found to be related to the degree of curing. High press temperatures and longer pressing times lowered the acidity of waferboards further. Figure 19 also illustrates this effect. It is interesting to note that one of the commercial waferboard has a pH of 4.2 (16).

High acidity in auto-bonded waferboard could have a long term effect on board strength and also may promote a corrosive effect on nails and other hardwares in the application of panels. For these reasons, some users specify a minimum pH of 3 for composite products (17). Kollman and Hoffman state that acidity at a pH above 2 has little degrading effect upon wood (18 and 19). This is consistent with the practice of using wood tanks to store acid. Since western red cedar and oak are known to have a pH of 2.45 and 3.5 respectively, and a Canadian commercial particleboard made from western red cedar is known to have a pH of 3.3, auto-bonded waferboard with a pH range of about 3.8 to 4.2 may not have any long-term adverse effect on wood and metal (20). In a previous study on sulfuric acid catalized sulfite pulping waste liquor as a binder for waferboard, it

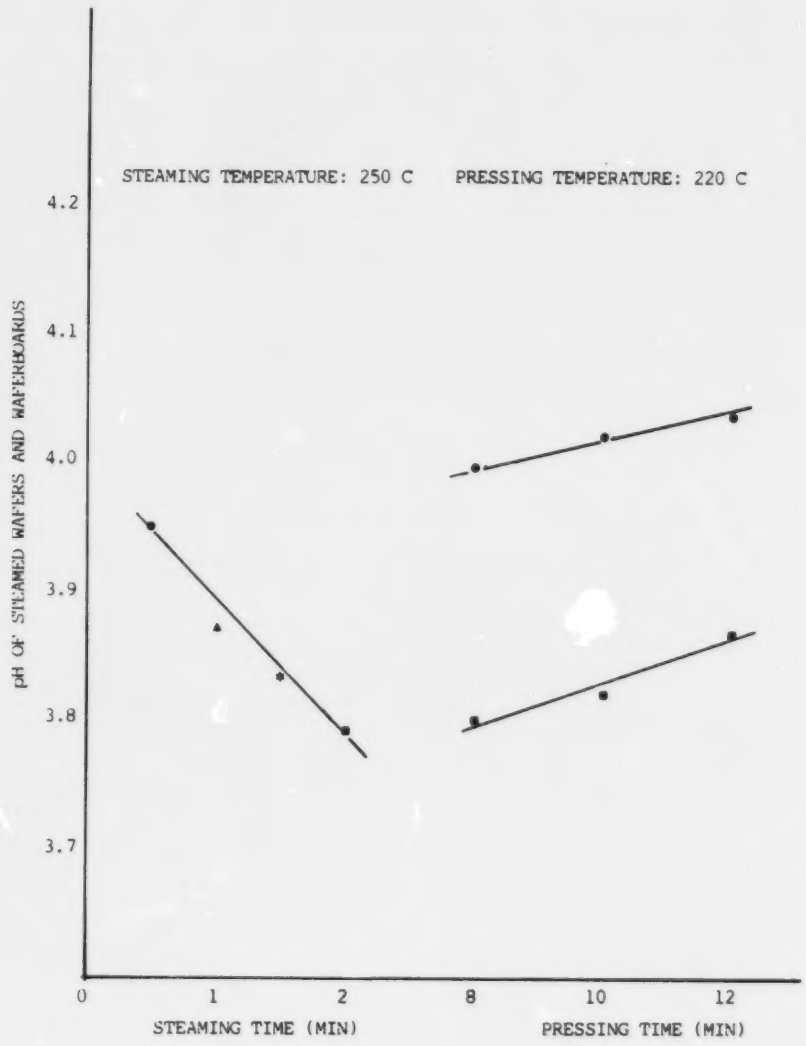



FIGURE 20. ACIDITY OF STEAMED WAFER AND WAFERBOARD

was found that the highly acidic waferboard with a pH of 3.8 to 2.8 showed no sign of adverse effect on panel durability (16). Furthermore, it should be pointed out that the acidity in the auto-bonded waferboard is organic in nature and is uniformly distributed within wafers, unlike the the conventional waferboard in which acid is mainly concentrated in the glue lines. However, further studies should be carried out on the long term durability of the auto-bonded waferboard in comparison with the conventional waferboard.

## 4.16 Caul Plate Sticking

Steamed wafers tended to have a sticking problem. Wafers treated with high steaming temperatures and longer steaming times appeared to cause more caul plate sticking than wafers treated with less intensity. High platen temperatures, high board densities and high moisture contents also contributed to the caul plate sticking. However, this problem was solved by coating the caul plates with a releasing agent. A silicon based releasing agent was usually sufficient in preventing sticking. One coat of releasing agent normally lasted for a number of pressings.

## 4.17 Colour of the New Waferboard

The steam treatment always turned the pale creamy poplar wafers into a light to dark chocolate brownish colour. It appears that the brownish colour was caused by the presence of hydrolyzed lignin and hemicellulose products. The intensity of colour was determined by the severity of the steam treatment. Higher steaming temperatures in combination with longer steaming times always produced darker wafers. The

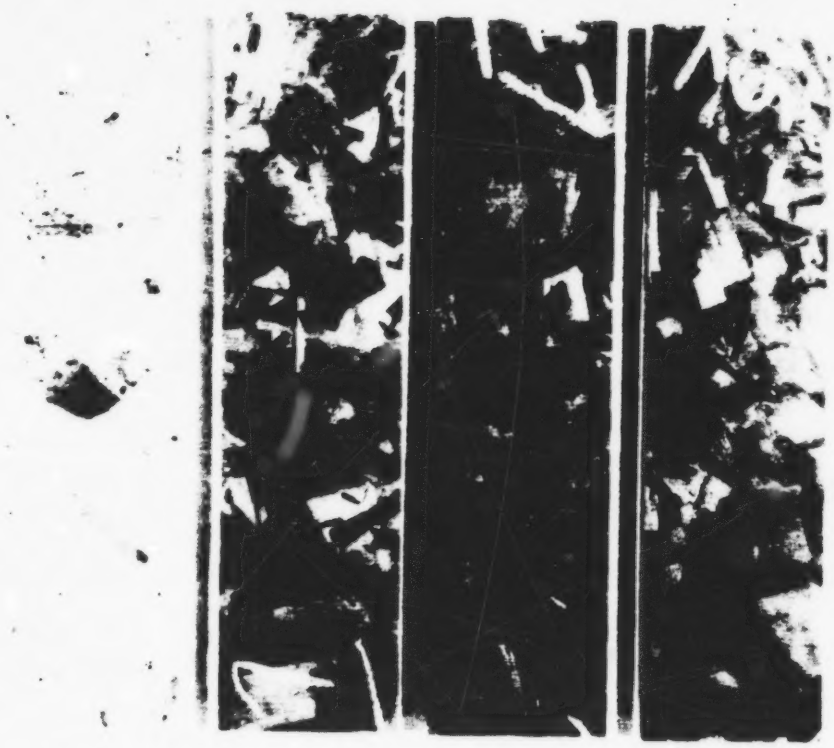


FIGURE 21. THE COLOUR OF WAFERBOARDS

brownish colour was further darkened after hot-pressing. Figure 21 shows the colour difference between a commercial waferboard and waferboards made from the steam treated wafers. Higher platen temperatures and longer pressing times also slightly increased the intensity of colour.

## 4.18 Dimensional Stability and Hygroscopicity

As expected, the new waferboard was less hygroscopic, in comparison to the ordinary phenolic bonded waferboard, particularly in humid conditions. For example, the new waferboard when exposed to 65% R.H. at 20 degrees C, maintained an equilibrium moisture content in the range of 4 to 5%, whereas the conventional phenolic bonded waferboard would have the EMC of approximately 6 - 8%. This lower hygroscopicity was believed to be responsible, at least in part, for the superb dimensional stability of the waferboard, which can be clearly seen in Figures 22 and 23.

In the natural state hemicellulose constitutes 20 - 30% of the weight of the lignocellulose and is amorphous in form; therefore, it has a greater affinity for water, resulting in dimensional changes when wood is exposed to moisture. On the other hand, the steam treated wafers were almost free from the natural hemicellulose and consequently, the auto-bonded board was found to be less hygroscopic than its constituents in their natural state. Furthermore, the water soluble carbohydrates of low molecular weight derived from the hydrolysis of the hemicellulose also permeated into the cell wall of the cellulose fibre and created a bulking effect, thus reducing the access of moisture to the cellulose. The high plasticity of the steamed wafers appeared to have a superior rheological property which requires relatively low unit pressure during hot pressing

FIGURE 22. SWELLING OF WAFERBOARDS

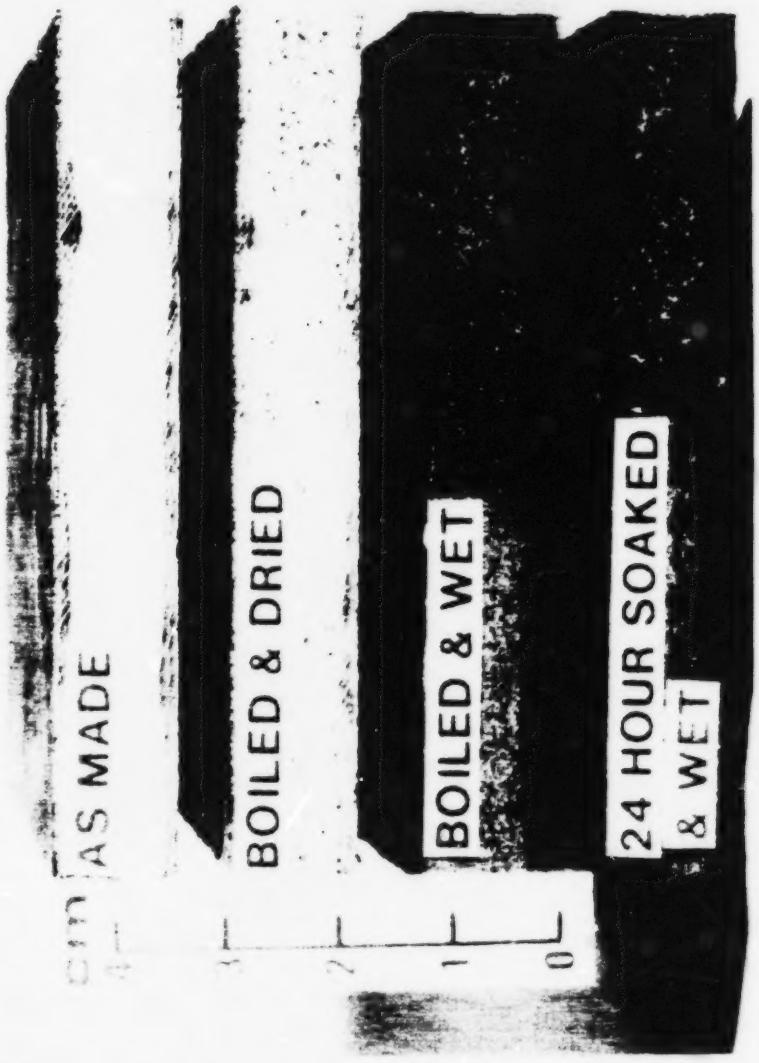



FIGURE 23. SWELLING OF A 3-LAYER BOARD (WAFER-FIBRE-WAFER)

to consolidate into a waferboard with virtually no springback. Apart from these, severe steam treatment and intense press conditions also enhanced the dimensional stability of the auto-bonded waferboard. These combined effects contribute to the superb dimensional stability of binderless waferboard in terms of thickness swelling. Linear expansion of the auto-bonded waferboard appeared to be less affected by the process. No differences were found in linear expansion as far as processing parameters were concerned; i.e. a severe steaming treatment or an intensive press condition failed to detect any improvement in linear expansion of auto-bonded waferboard. In general, linear expansion of the new waferboards was found to be slightly better than that of the conventional phenolic bonded waferboard.

## 5. ECONOMIC CONSIDERATIONS

### 5.1 Steam Consumption

Steam consumption was basically related to the intensity of the treatment; however, steam consumption was also determined by the initial moisture content of the green wafers: the higher the moisture content, the greater the steam consumption. Table 6 lists the steam consumption determined for wafers containing different initial moisture contents treated under varying conditions. These figures were somewhat higher than the values expected from theoretical calculations. This discrepancy was most likely caused by the higher rate of heat loss from the pressure vessel and the nature of the batch operation. A lower consumption of steam was realized when the steam treatment was carried out in the chamber of the steam press which was better insulated than the larger vessel.

TABLE 6

STEAM CONSUMPTION

| Steam Condition | | Steam Consumption (% by wt. of O.D. Wafers) | |
|---|---|---|---|
| Temp/Time Deg C/Min | M.C.% | Big Vessel | Steam Press Chamber |
| 240/1 | 100-120 | 216 | 192 |
| 2 | | 242 | 223 |
| 3 | | 256 | 237 |
| 240/1 | 15-20 | 156 | 132 |
| 2 | | 177 | 157 |
| 3 | | 192 | 160 |
| 220/2 | 100-120 | 187 | 167 |
| 4 | | 196 | 182 |
| 6 | | 222 | 208 |
| 220/2 | 15-20 | 149 | 132 |
| 4 | | 172 | 155 |
| 6 | | 202 | 182 |

Similarly, steam consumption would be reduced if the treating procedure could be automated for continuous processing. Likewise, the energy from the spent steam would normally be recovered in a commercial process, reducing overall energy consumption.

## 5.2 Economical Prospects

The auto-bonding process completely eliminates the use of synthetic resin and wax and allows for the use of low cost mill residue for the core stock. In the commercial production of phenolic bonded waferboard, wood material, phenolic resin and wax in general constitute almost 46% of the total production cost for waferboard. The elimination of synthetic resin and wax from auto-bonded waferboard will lower the production cost by about 21%. Replacing 50% or more of the wafers by the low cost mill residue will further reduce production costs by 16%. Combined savings from elimination of phenolic resin, wax and the change in wood material during the production of auto-bonded waferboard is estimated at 37% of the total production cost of commercial waferboard.

The auto-bonding process consumes more heat energy because of requirement for the steam pretreatment, the longer press time and thinner wafers. Processing steam in the conventional forest products industry is normally generated from mill residues at a current price about 2 to 4 dollars per ton. Two tons of steam are required to treat one ton oven dry wafers, which translates to an estimated increase of approximately 3% in production costs. The longer pressing times and higher platen temperatures would also increase production costs by another 2%. These are two additional expenses i.e. extra energy consumption, in the production of the auto-bonding waferboard. The production cost for

thinner wafers is readily offset by the reduction in the volume of thinner wafers to be used as in the production of a 3-layer waferboard. In a 3-layer waferboard more than 50% wafers by weight will be replaced by low cost mill residues in the core layer. The balance is clearly in favour of the new process with net savings amounting to an estimated 32% of the total production cost. Table 6 illustrates the comparative production costs for the conventional and the auto-bonding process for making waferboard.

Auto-bonding waferboard appears to perform better at relatively high densities. This high density board will increase material by 5-10%. In addition there is a mass loss involved in the steam treatment and in the hot pressing, which may amount to 7-10% by weight. Extra wood material in the order of 12 - 20% by weight is required to compensate for the high density board and mass loss. This can be partially offset by the total utilization of poplar logs and saw mill residues. In the production of conventional resin and wax bonded waferboard, there is a 7 - 10% rejection of under-sized wafers and fines generated during waferization. Normally these rejected particles are used as fuel which is not particularly economically desirable. However, with auto-bonding, all rejected material can be used along with saw mill residues as core stock. The additional consumption of wood material required by the auto-bonding process will be substituted by the low cost mill residue which will increase the overall production cost by 1-2%.

Table 7 illustrates the comparative production costs for the conventional and the auto-bonding process for making waferboard. Based on the data listed in Table 7 and with those discussed in this report, it is evident that auto-bonded waferboard can be produced at a more economical

Table 7

COMPOSITE PANELS PRODUCTION COST COMPARISON

94,000 $M^3$/Year Plant (CAN$28-32 Million)*

$ Can/$M^3$

| | Conventional Process | | | Dr. Shen's Process | |
|---|---|---|---|---|---|
| Plant Type | MDF | PB | WF | MDF | WF |
| Raw Material | Wood Waste | Wood Waste | Round Wood | Wood Waste | Round Wood Wood Waste |
| Fiber | 6.62 | 7.21 | 43.08 | 6.62 | 24.85 |
| Resin | 41.35 | 31.69 | 28.11 | -- | -- |
| Wax | 2.55 | 3.66 | 5.47 | -- | -- |
| Labour | 19.51 | 19.50 | 26.12 | 19.51 | 19.50 |
| Supplies | 9.60 | 9.04 | 8.44 | 9.60 | 8.44 |
| Electrical | 7.06 | 4.85 | 5.69 | 7.06 | 5.69 |
| Fuel | .42 | .37 | -- | 3.12 | 3.37 |
| Natural Gas | 7.32 | 5.65 | -- | 11.11 | 10.85 |
| Variable Costs | 94.43 | 81.97 | 116.91 | 55.02 | 79.32 |
| Superv. & Admin. | 5.60 | 5.60 | 5.60 | 5.60 | 5.60 |
| Office O.H. | 2.68 | 2.68 | 2.68 | 2.68 | 2.68 |
| Ins. & Taxes | 4.80 | 4.46 | 4.80 | 4.80 | 4.46 |
| Depreciation | 31.90 | 29.80 | 34.00 | 31.90 | 29.80 |
| Fixed Costs | 44.98 | 42.54 | 47.08 | 44.98 | 42.54 |
| Total Comparative Costs | 140 | 125 | 164 | 100 | 112 |
| Cost Saving | 40 | 25 | 52 | — | -- |

Note: MDF- Medium density fibreboard

PB - Particleboard

WF- Waferboard

* - 1985 Figures

rate than conventional waferboard. The difference in production cost is about 32%, indeed, a very significant amount.

## 6. ENVIRONMENTAL CONCERN

Powdered phenolic resin has been used exclusively in the production of waferboard since its inception in Canada in 1961 even though the powdered phenolic resin is more expensive than it is in liquid form. This is because the same amount of liquid resin will not be able to cover the surfaces of wafers evenly and uniformly in order to provide good interface bonding. This is a very fine powder which will pass through a 325 mesh screen. In order to stabilize the powder on the surfaces of wafers, molten slack wax, in an amount of 1.5 -2 % by weight of O.D. wafers must be applied to make the fine resin powder stick to the wafers. Without the wax spray, the fine powdered resin becomes dislodged from the wafers and air borne. This creates a very dusty working environment inside the plant, particularly in the blending area, causing health concerns. The spraying of wax has, essentially, a dual function in waferboard production; that is to retard moisture penetration of the waferboard and to stabilize powdered resin during the manufacturing process. Even with the spray of slack wax, resin dusting still poses a great environmental concern. Auto-bonding will entirely eliminate this problem.

## 7. CONCLUSIONS

1. By pretreating the green poplar wafers with a high pressure steam for a short period of time, by auto-bonding, a boilproof waferboard can be produced without the use of a synthetic resin.

2. Auto-bonding is achieved by the transformation and polymerization of the water soluble carbohydrates derived from the decomposition and hydrolysation of the hemicellulose fraction of poplar wafers during the steam treatment.

3. An appropriate combination of steaming temperature and duration is essential to produce a suitable waferboard.

4. Thinner and smaller sized wafers result in a uniform mat and therefore, produce a better waferboard.

5. The density of the waferboard has a direct relationship to the mechanical strength. The auto-bonded waferboard requires a 42 to 44 pounds density (0.67 - 0,71 specific gravity), or 5-10% higher than the conventional phenolic bonded waferboard, to meet the new CSA standard.

6. The curing rate of auto-bonding waferboard is much slower than the conventional phenolic bonded waferboard and also requires twice the press time.

7. An acidic catalyst may be used to improve the curing time of auto-bonded waferboard.

8. The auto-bonded waferboard possesses superb dimensional stability and is less hygroscopic than the conventional phenolic bonded waferboard.

9. Overall steam consumption for the production of auto-bonded waferboard varies considerably, depending mainly on the initial moisture content of the green wafers.

10. The new process allows the use of low cost mill residues as the core

stock to produce a 3-layer waferboard with a core stock containing fibres and particles.

11. The new process has both technical and economical merits for commercial applications.

12. It is economically attractive and technologically viable to design and build a new plant for the production of auto-bonded waferboard. For any existing waferboard it may not be economically viable at present to adopt this new process because of the long press times required for the auto-bonded waferboard.

## 8. RECOMMENDATIONS

1. It is recommended that the R & D work of this project be continued and scaled up to a trial production in order to make full sized auto-bonded binderless waferboards for various acceptance tests and trial applications before carrying out a commercial plant trial production.

2. A 3-layer waferboard incorporating mill residues as core stock should be further examined in more detail.

3. Special attention should be given to the design and fabrication of a high pressure steam vessel for treating the green wafers.

4. Further investigation of a catalyst or other methods for accelerating the curing rate should be conducted in order to provide a comparable press schedule with commercial manufacturing.

5. The effect of auto-bonding on the long term durability of the new waferboard, particularly with regard to the use of acidic catalyst should be examined.

6. Any further work relating to commercial application of the new auto-bonding process should involve the waferboard industry.

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